STRUCTURAL CALCULATION OF DIVERSION TUNNEL LINING

[UPPER TRISHULI-1 HEP (216MW)]

2022. 10. 13

DOOSAN Doosan Heavy Industries & Construction

FOR APPROVAL

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Project

Upper Trishuli-1 HEP (216MW)

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1 General

1.1 Background

Upper Trishuli-1 HEP is a project that uses the Trishuli River near Dunche and Haku. The construction site is located at rugged mountain between Tibet in China and the Himalaya Mountain which place 70 km away from capital, Kathmandu, towards the northwest. The headwork site is at 280m downstream from the confluence of Bhotekoshi and Trishuli rivers. The powerhouse site is 500m upward from Mailun Dobhan where Haku VDC is placed. The installed capacity of Upper Trishuli-1 HEP is 216 MW as a Run of River type. It is a year-round power plant which can generate about 1,533.4 GWh within a year.

The diversion tunnel is located on the right bank of Trishuli River. The cross section is a reversed 'D' shaped type (rectangular shape plus an arc section). The elevation of the inlet is EL. 1244.50m, and the elevation of outlet is EL. 1231.00m. The length of diversion tunnel is about 413.042 m and the longitudinal slope is 3.32%.

The profile of diversion tunnel is shown in Figure 1.1. The cross section is shown in Figure 1.2~1.6.

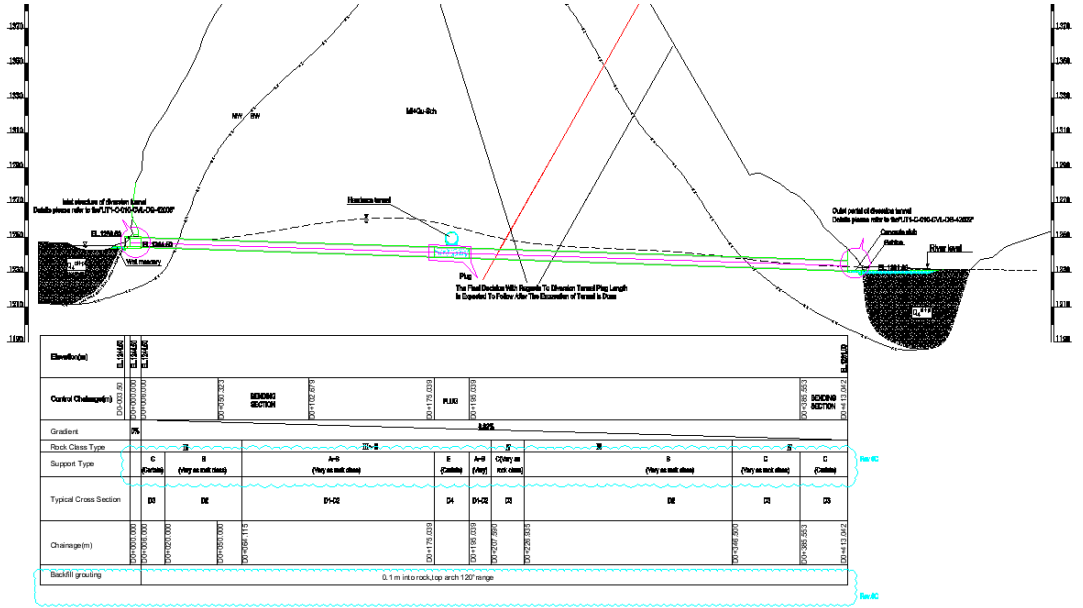


Figure 1.1 Profile section of diversion tunnel

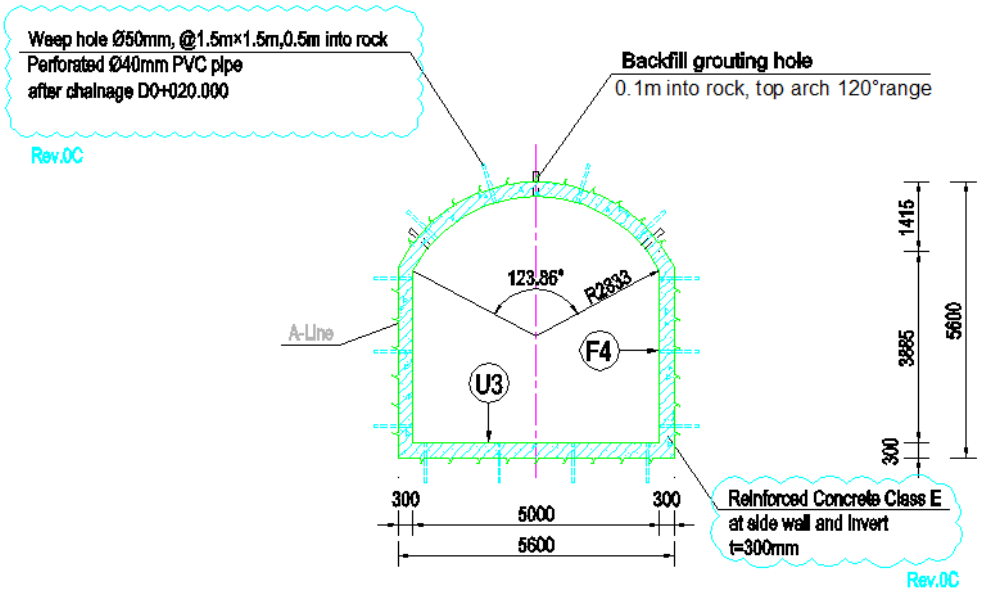


Figure 1.2 Typical section of diversion tunnel (Rock class II)

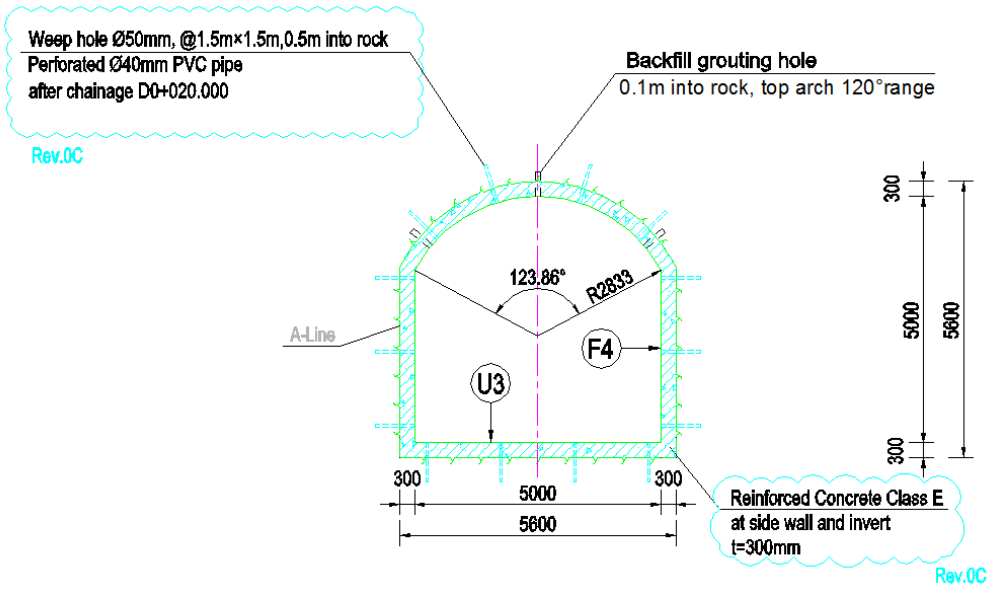


Figure 1.3 Typical section of diversion tunnel (Rock class III, 300mm liner)

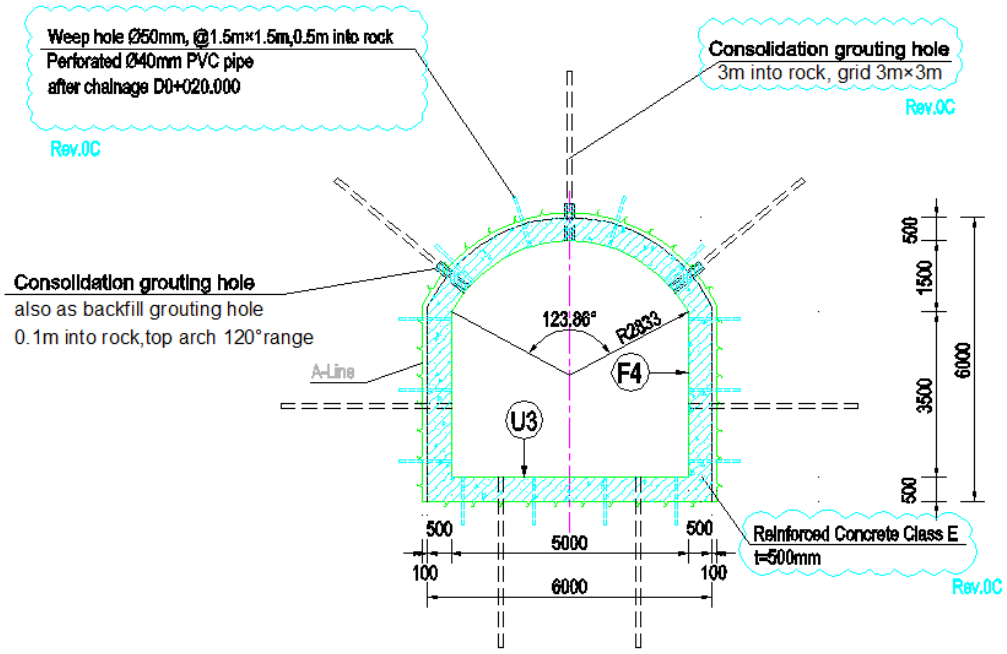


Figure 1.4 Typical section of diversion tunnel (Rock class III, 500mm liner)

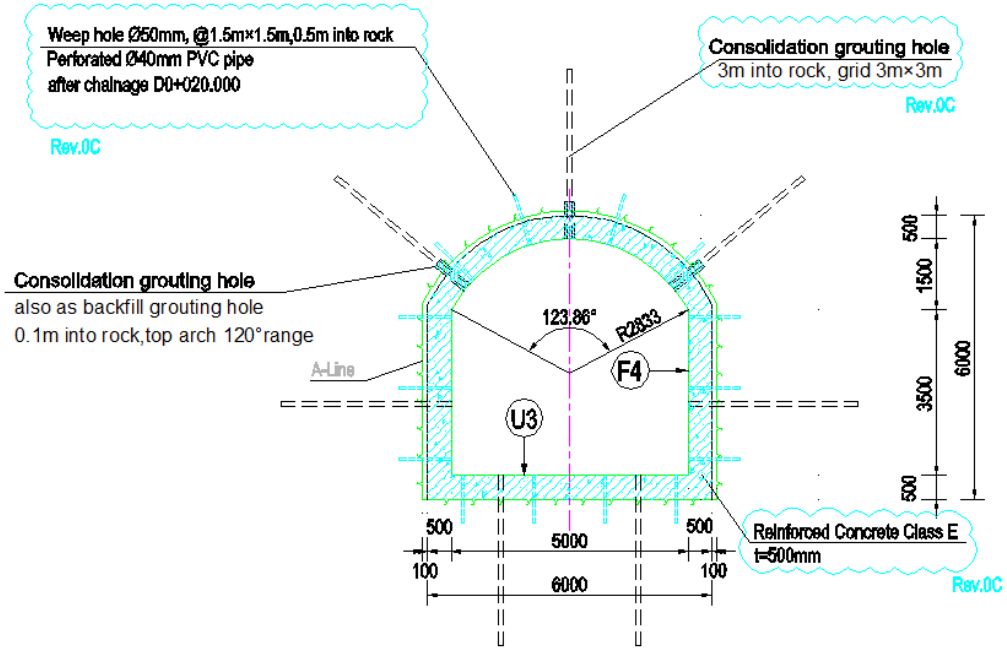


Figure 1.5 Typical section of diversion tunnel (Rock class IV)

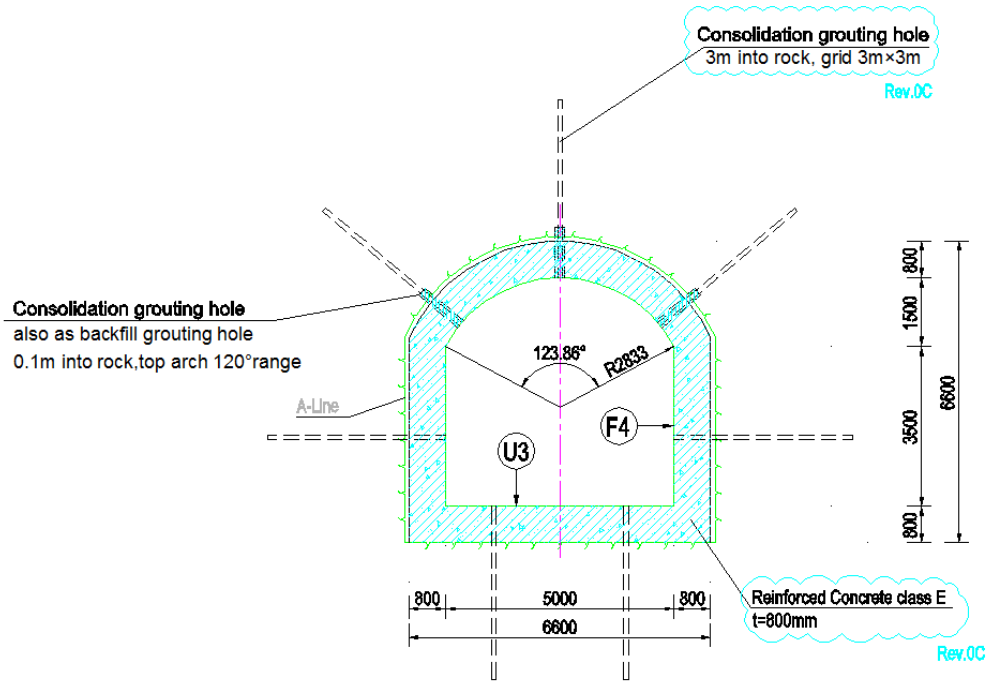


Figure 1.6 Typical section of diversion tunnel

(Intersection of headrace and diversion tunnel)

1.2 Design stage & software

This calculation is provided for detailed design stage.

The internal force (bending moment, axial force, and shear force) is calculated by Midas Gen, MIDAS Gen is a 3D structural analysis and design system from MIDAS, the company's first commercial software. Its powerful calculation and analysis function meets the calculation and design requirements of conventional buildings, and it can also well complete the analysis and design of mixed structures and special structures.

1.3 Purpose and contents

Internal force of tunnel cross section is calculated with representative chainage in line with arrangement of Diversion Tunnel, category of surrounding rock and water pressure, according to which reinforcements are configured to provide the basis for detail design of Diversion Tunnel. Please refer to Table 1.1 for table of chainage at control section of Diversion Tunnel.

Table 1.1 Table of chainage at control section of diversion tunnel

No.	Starting chainage No.	Ending chainage No.	Surrounding Rock Class	Thickness of Lining (m)
1	D0+006.00	D0+020.000	III	0.5
2	D0+020.000	D0+064.115	III	0.3
3	D0+064.115	D0+175.039	II-III	0.3
4*(1)	D0+175.039	D0+195.039	II-III	0.8
5	D0+195.039	D0+207.590	II-III	0.3
6	D0+207.590	D0+226.935	IV	0.5
7	D0+226.935	D0+346.500	III	0.3
8*(2)	D0+346.500	D0+413.042	III	0.5

Note: No. 4* is intersection of headrace and diversion tunnel; No.8* it is speculated to be rock class IV in bidding stage, but the actual excavation rock class is III.

2 Reference Document

2.1 Rules and regulations

(1) Tunnels and Shafts in Rock (EM 1110-2-2901);

(2) Strength Design for Reinforced Concrete of Hydraulic Structure (EM1110-2-2104);

(3) Building Code Requirements for Structural Concrete (ACI 318);

(4)ASCE Vol 2-Civil Engineering Guidelines for Planning and Designing Hydroelectric Developments-Water ways;

(5) Erosion of Concrete in Hydraulic Structures (ACI 210R-06).

2.2 Technical documents

(1) Arrangement Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42001)

(2) Hydraulic Calculation fo Diversion Tunnel (UT1-C-010-CVL-DC-42001)

(3) Excavaiton and Initial Support Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42003)

(4) Outline Drawing of Diversion Tunnel (UT1-C-010-CVL-DG-42005)

3 Calculation Process

3.1 Material characteristics and calculation parameters

(1) Concrete

a) Volume weight of reinforced concrete: 25.0kN/m³;

b) Elastic modulus and Poisson's ratio are shown in Table 3.1-1.

Table 3.1-1 Elastic modulus and Poisson's ratio

Cylinder compressive strength (MPa)	Location	Elastic Modulus E_c (MPa)	Poisson's Ratio
24	Side wall and roof	2.3×10^4	0.2
30	Invert	2.57×10^4	0.2

(2) Reinforcement

a) Yield strength of deformed bar: 500MPa;

b) Elastic modulus: 200,000MPa;

c) Concrete covers of reinforcement are shown in Table 3.1-2.

Table 3.1-2 Concrete cover of reinforcement

Location	Water side cover(mm)	Rock side cover(mm)
Side wall and roof	75	75
Invert	150	75

(3) Physical and mechanical parameters of rocks

Table 3.1-2 Mechanical parameter of diversion tunnel surrounding rock

Class of surrounding rock	Saturated compressive strength	Elastic modulus	Poisson's ratio	Rock mass/rock mass shear (shearing) strength	
	(MPa)	(GPa)	v	Φ (°)	c′ (MPa)
II	13	20.5	0.25	48	2.5
III	4.2	7.5	0.27	45	1.0
IV	1.9	2.3	0.30	35	0.5

3.2 Calculation principle and method

The calculation takes the method of bedded-beam-spring recommended in Chapter 9 of EM 1110-2-2901 Tunnels and Shafts in Rock that simulates lining section with MIDAS beam element and the arc length corresponding to every 5° central angle or less as the unit length and simulates interaction between lining and surrounding rock by applying normal and tangential point spring supports to nodes. Reinforcements of lining section are configured according to result of internal force calculation. Figure 3.2-1 is illustration of concrete lining model.

Stiffness of point spring support is calculated by the following formulas:

For normal stiffness

$$k_r = E_r b\theta/(1+\nu_r)$$

For tangential stiffness

$$k_t = k_r G/E_r = 0.5k_r/(1+\nu_r)$$

Wherein:

k_r and k_t: Normal and tangential stiffness of springs; kN/m

E_r: Elastic modulus of surrounding rock; kPa. shown in the Table 3.2-1.

θ: Central angle of beam element; radian, 5 degree.

b: Unit length along tunnel; m.

G_r : Shear modulus of surrounding rock; kPa.

ν_r : Poisson's ratio of surrounding rock

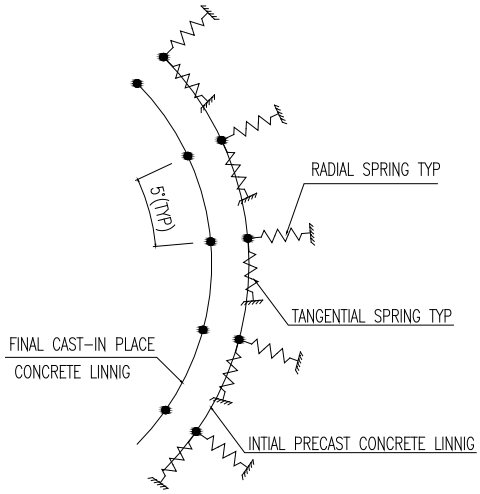


Figure 3.2-1 Illustration of concrete lining model

The method is regarding MIDAS program advance instruction book.

According to formulas in section 3.2, normal stiffness and tangential stiffness of rock class II, rock class III and rock class IV are as listed in Table 3.2-1.

Table 3.2-1 Normal and tangential stiffness of surrounding rock

Rock class	Normal Stiffness k_r (calculated with elastic modulus) (kN/m)	Tangential Stiffness k_t (calculated with elastic modulus) (kN/m)
Rock class II	1431170	572468
Rock class III	515353	202895
Rock class IV	154395	59383

In Midas Gen software, the model element is about 0.25m. The z-direction displacement constraint is applied outside the plane. And the point spring constraints are used in the plane. The calculation elements dividing are as follows.

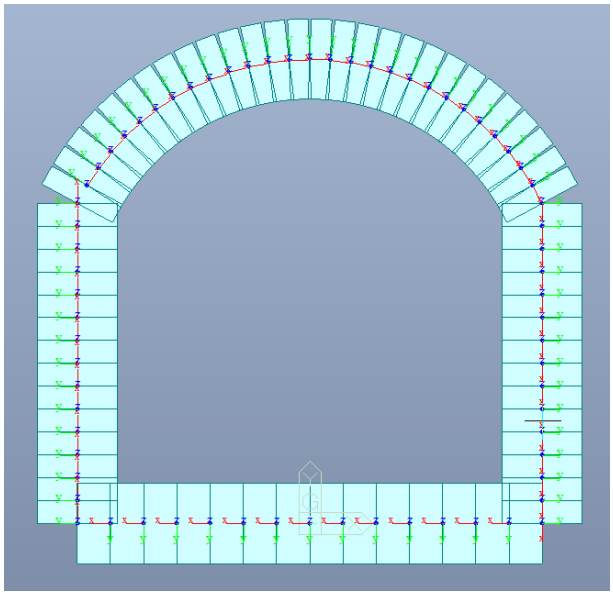


Figure 3.2-2 Elements of full concrete lining model

3.3 Combination of working conditions and calculation of loads

3.3.1 Combination of working conditions

According to table 9-1, EM1110-2-2901, loads acted on the lining include lining self-weight, internal water pressure, external water pressure, surrounding rock load, etc.

Additionally, it is reminded that according to the U.S.A.C.E. Manual EM 1110-2-2901, paragraph 9.4, item f: “In most cases, the rock is stabilized at the time the concrete lining is placed, and the lining will accept loads only from water pressure (internal, external, or both)."

There are four circumstances when other loads are considered and they are listed as follows:

--Uneven support caused a thick layer of rock of much lower modulus than the surrounding rock, or a void left behind the lining;

--Uneven loading caused by a volume of rock loosened after construction, or a localized water pressure trapped in a void behind the lining;

--Displacements from uneven swelling or squeezing rock;

--Construction loads, such as from non-uniform grout pressures.

To the diversion tunnel of this project, none of them is applicable, so the rock load will not be considered in the calculation.

During the construction such as temporary deformation monitoring measures should be installed, the concrete lining is casting after deformation finish.

Loads and combination of working conditions are as stated in Table 3.3-1 and load factor under respective working condition is as listed in Table 3.3-2. And load sketches in each case are as follows.

Table 3.3-1 Operation conditions and relevant loads

No.	Working Condition of Calculation	Self-weight	Internal water Pressure	External water Pressure	Grouting pressure
CASE1	Construction of D/T	√			√
CASE2	Normal operation	√	√	√	
CASE3	Dry season operation	√	√	√	

Note:

1. For lining and segment lining with weep holes, the internal pressure equals to the external pressure, thus the water pressure acting on the lining takes zero. However for lining and segment lining without weep holes, external water pressure is not considered.

2. As for the lining without weep holes, the counteracting effect of external water pressure on internal water pressure is not considered. The force acting on the lining adopts the whole internal water pressure.

Table 3.3-2 Load factor under every working condition

No.	Working Condition of Calculation	Self-weight	Internal water Pressure	External water Pressure	Grouting pressure
CASE1	Construction of D/T	1.1	/	/	1.4
CASE2	Normal operation	1.3	1.4	1.4	
CASE2	Dry season operation	1.3	1.4	1.4	/

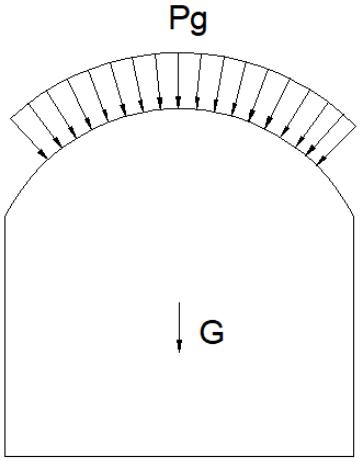


Figure 3.2-3 load sketch in case 1: self-weight load G, grouting pressure Pg

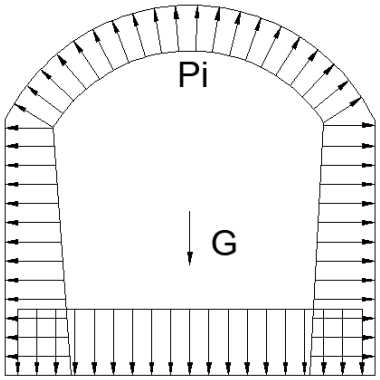


Figure 3.2-4 load sketch in case 2: self-weight load G, normal internal pressure Pi

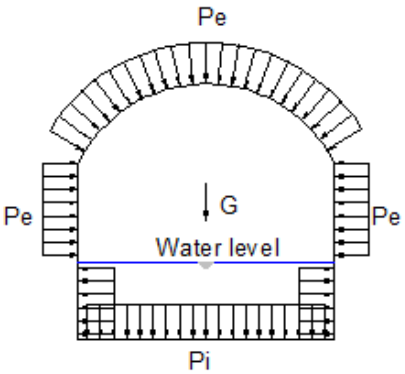


Figure 3.2-5 load sketch in case 3: self-weight load G, normal internal pressure Pi, normal external pressure Pe

3.3.2 Calculation of Loads

(1) Internal water pressure for normal operation

According to Hydraulic Calculation fo Diversion Tunnel, the inlet water level of diversion tunnel is at EL.1260.5m (5-year return period flood in whole year) , inlet invert is at EL.1244.5m and corresponding water head is 16.5m (measuring from the bottom of invert).

The outlet water level of diversion tunnel is at EL.1238.20m (5-year return period flood in whole year) ,outle invert is at EL.1231m and corresponding water head is 12.4m.

The maximum water head 16.5m is chosen as the designing internal pressure in normal operation case.

In diversion tunnel construction period, the diversion tunnel is empty inside,and the internal water pressure is zero.

According to Hydraulic Calculation fo Diversion Tunnel, the inlet water level of diversion tunnel is at EL.1251.39m (20-year return period flood in dry season) , for the convenience of calculation, the water level of the diversion tunnel is considered according to the normal water depth 2.7m.

The internal water pressure is as follows.

Table 3.3-3 Table of internal water head of control section for each case

No.	Control section Chainage	Surrounding Rock Class	Construction Internal water head/pressure (m)/(kPa)	Normal operation Internal water head/pressure (m)/(kPa)	Dry season operation Internal water head/pressure (m)/(kPa)
1	D0+020.000	III	0	16.5/161.70	*2.7/26.46*
2*	D0+195.039	II-III	0	16.5/161.70	*2.7/26.46*
3	D0+226.935	IV	0	16.5/161.70	*2.7/26.46*
4	D0+385.553	III	0	16.5/161.70	*2.7/26.46*
5	D0+413.042	III	0	16.5/161.70	*2.7/26.46*

(Note: No. 2* is intersection of headrace and diversion tunnel)

(2) Grouting pressure

According to EM 1110-2-2901 Ch 9-4. Design of permanent concrete linings item 8 in Box 9-1 "Non-uniform grouting load, or loads due to void behind lining: Use maximum permitted grout pressure over area equal to one-quarter the tunnel diameter, maximum 1.5 m" .

Considering that backfill grouting pressure is acted within 90° of roof, *grouting pressure is taken as 200kPa*.

(3) External pressure

Table 3.3-4 Table of external water head of control section for each case

No.	Control section Chainage	Surrounding Rock Class	Full external water head(m)	Head reduction factor	Dry season operation Internal water head/pressure (m)/(kPa)
1	D0+020.000	III	4.65	1	*4.65/45.57*
2	D0+195.039	II-III	12.88	Roof 1	*12.88/126.22*
				Side wall & invert 0.25	*3.22/31.56*
3	D0+226.935	IV	7.26	0.25	*1.82/17.84*
4	D0+385.553	III	18*	0.25	*4.50/44.1*
5	D0+413.042	III	1.13	0.25	*0.28/2.74*

(Note:* symbol means that in order to make the cross-section more representative and comprehensive, the maximum groundwater level is used here. For No.5 situation, the groundwater head is smaller than the internal water head, and it is treated according to the flat pressure due to the existence of drainage holes)

4 Calculation Result

4.1 Figure of internal force

All internal water pressure which induce a load into the tunnel lining are transferred into the surrounding rock, moreover there all weep holes on the tunnel lining, the inner water can seep into the surrounding rock. Then the inner and outer pressures of the lining are approximately equal, so the normal case is not critical. And the result of each case are listed as follows.

4.1.1 Figure of internal forces of concrete lining (Chainage 0+020.00)

The concrete lining from CH6.00 to CH20.00, class III, *concrete lining thickness 0.5m*, double-

sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

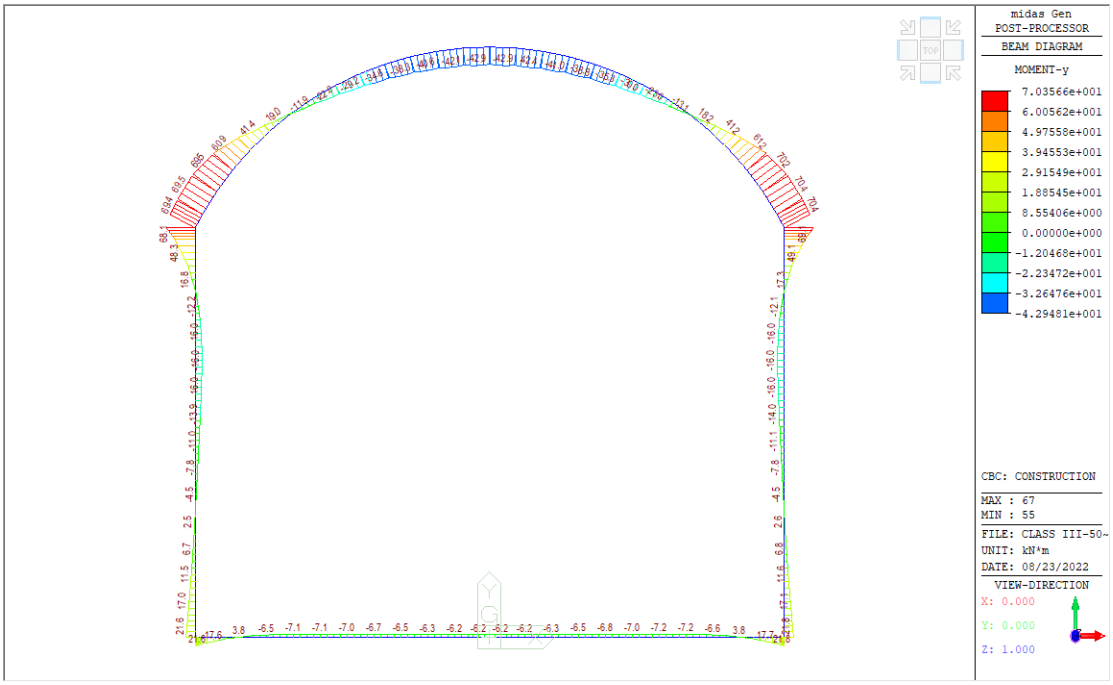


Figure 4.1.1-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

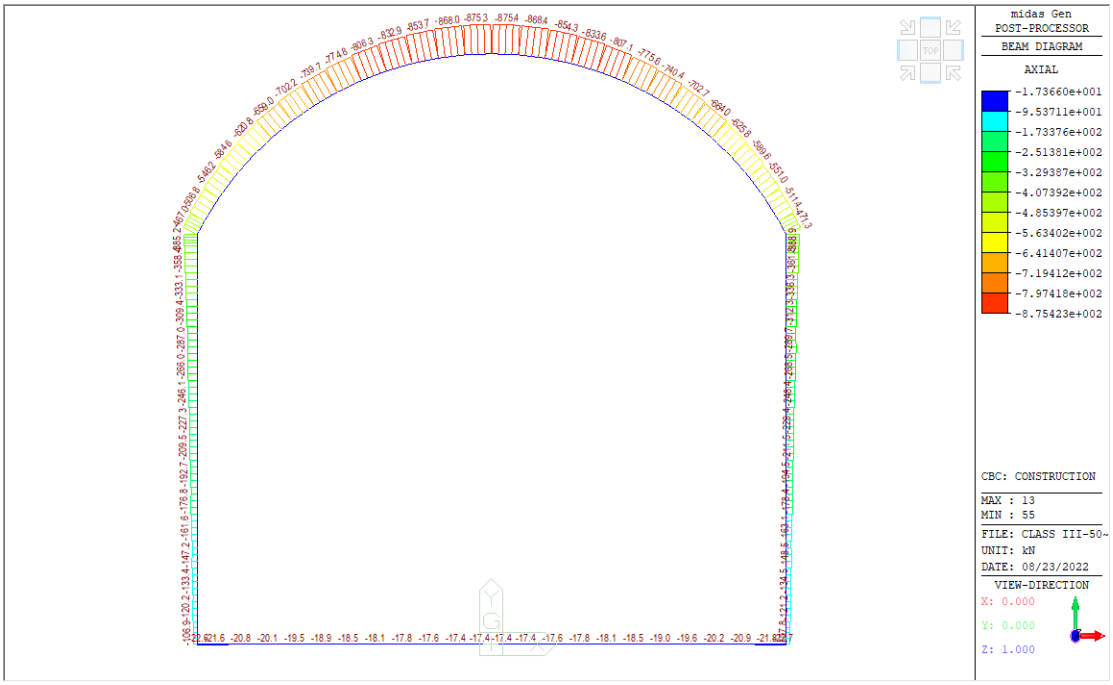


Figure 4.1.1-2 Figure of Axial Force at Concrete Lining Section (CASE1)

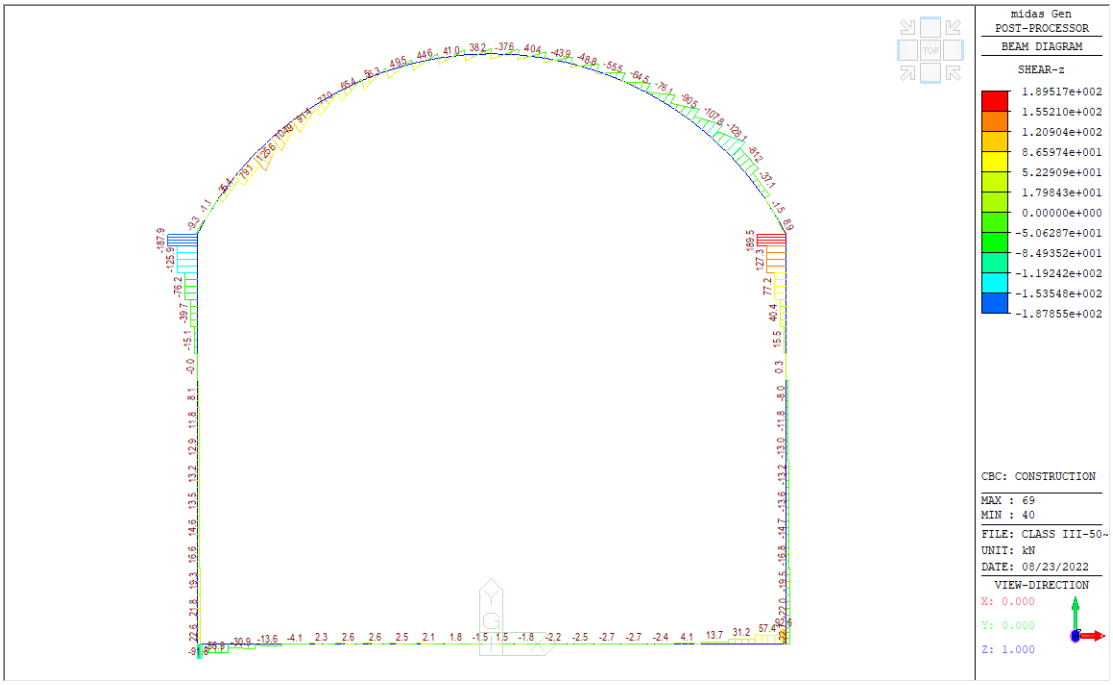


Figure 4.1.1-3 Figure of Shear Force at Concrete Lining Section (CASE1)

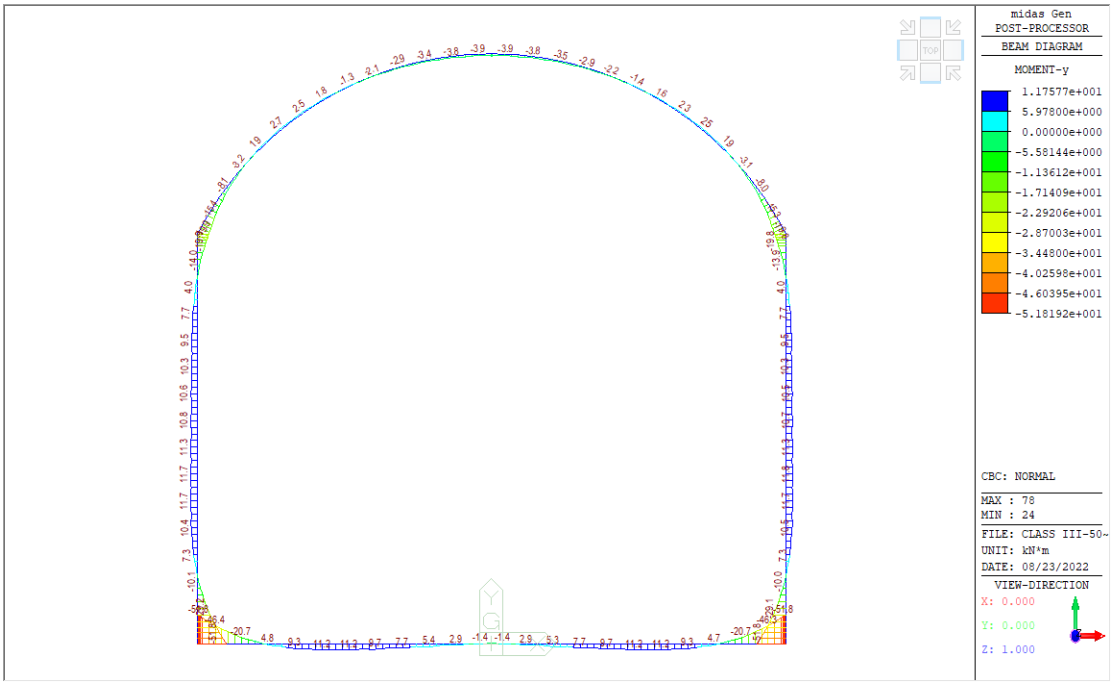


Figure 4.1.1-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

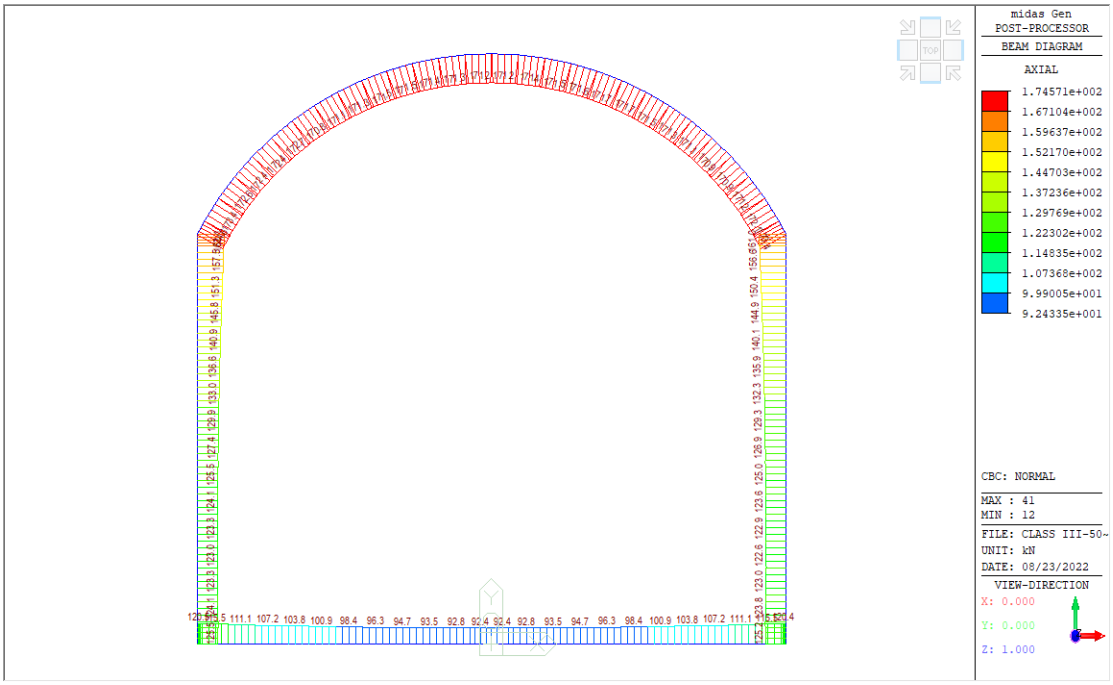


Figure 4.1.1-5 Figure of Axial Force at Concrete Lining Section (CASE2)

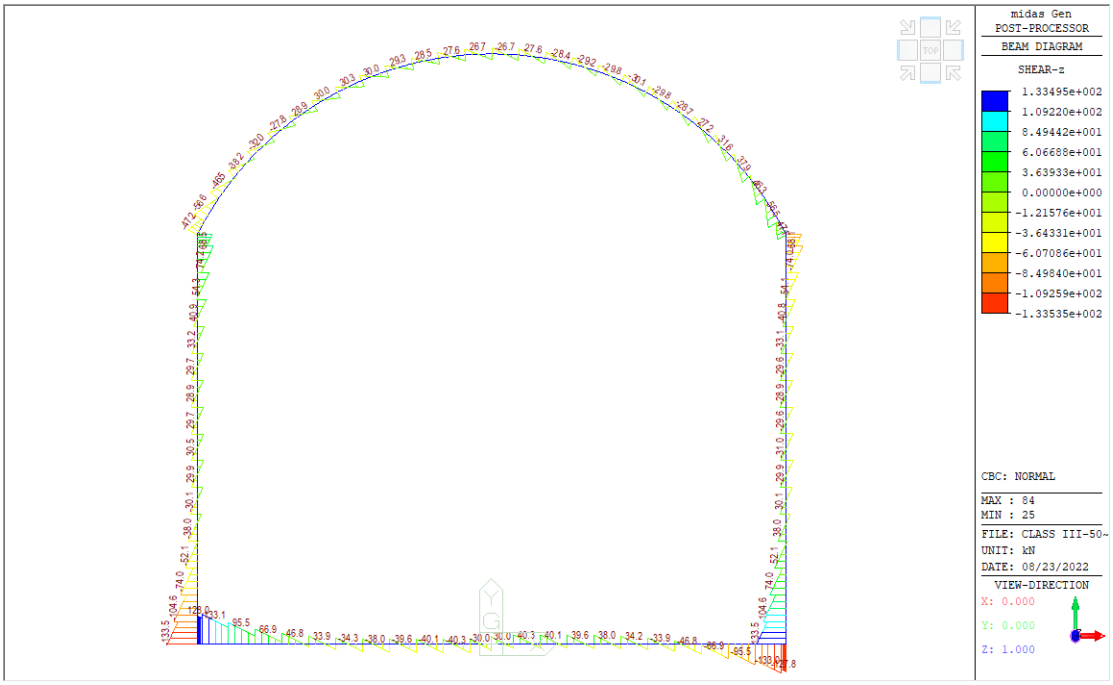


Figure 4.1.1-6 Figure of Shear Force at Concrete Lining Section (CASE2)

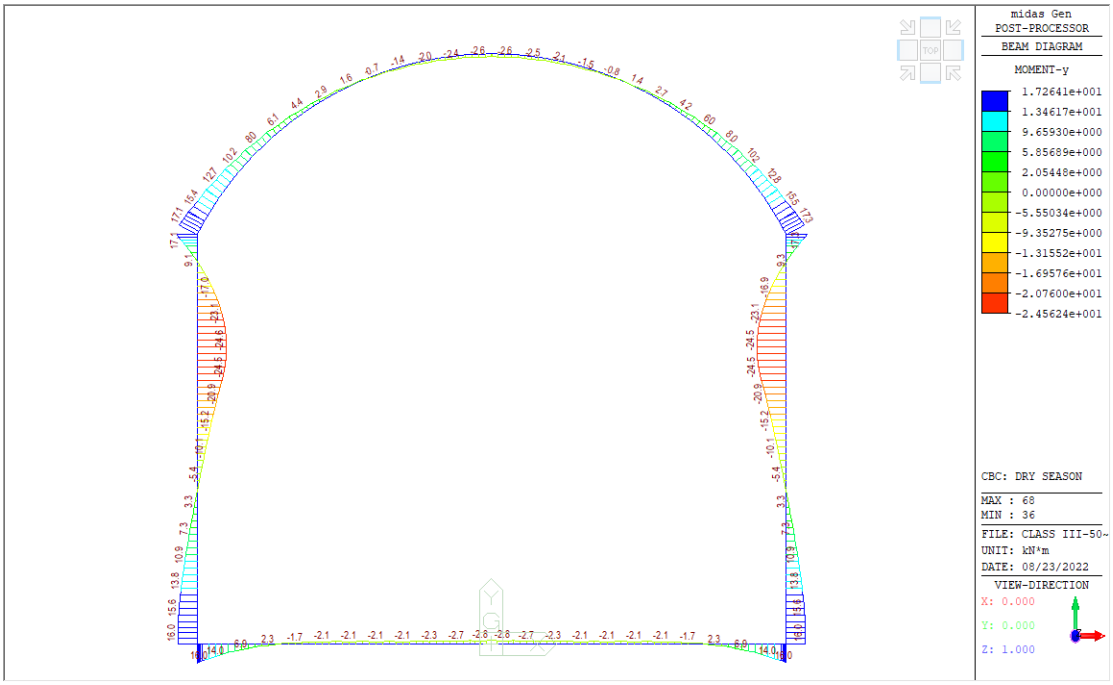


Figure 4.1.1-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

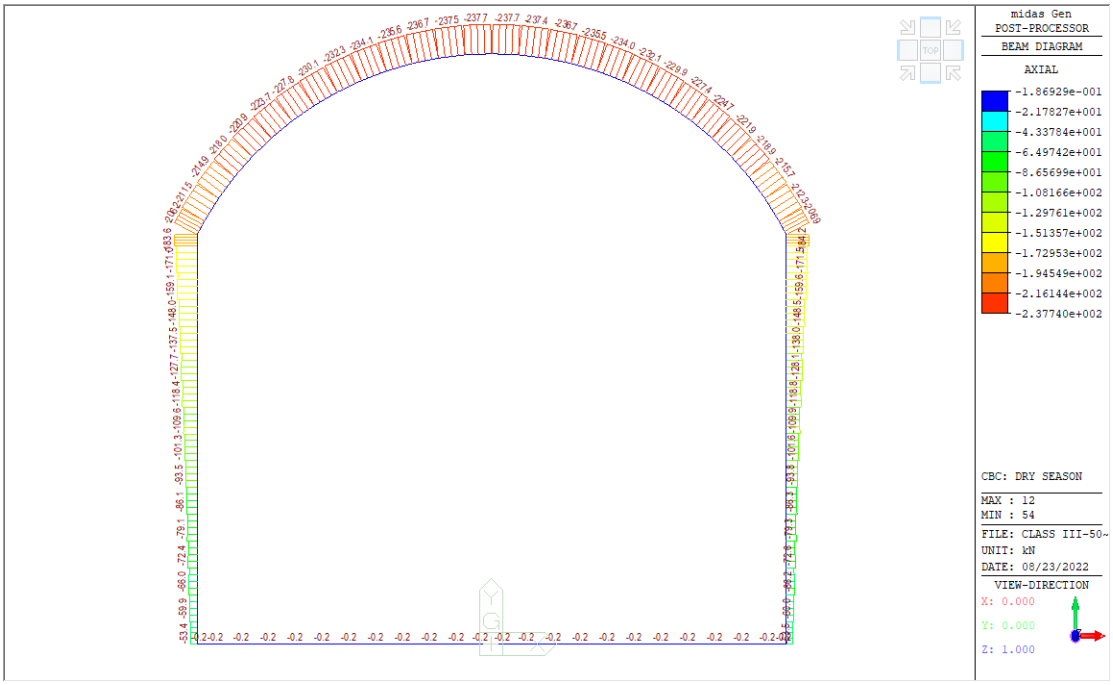


Figure 4.1.1-8 Figure of Axial Force at Concrete Lining Section (CASE3)

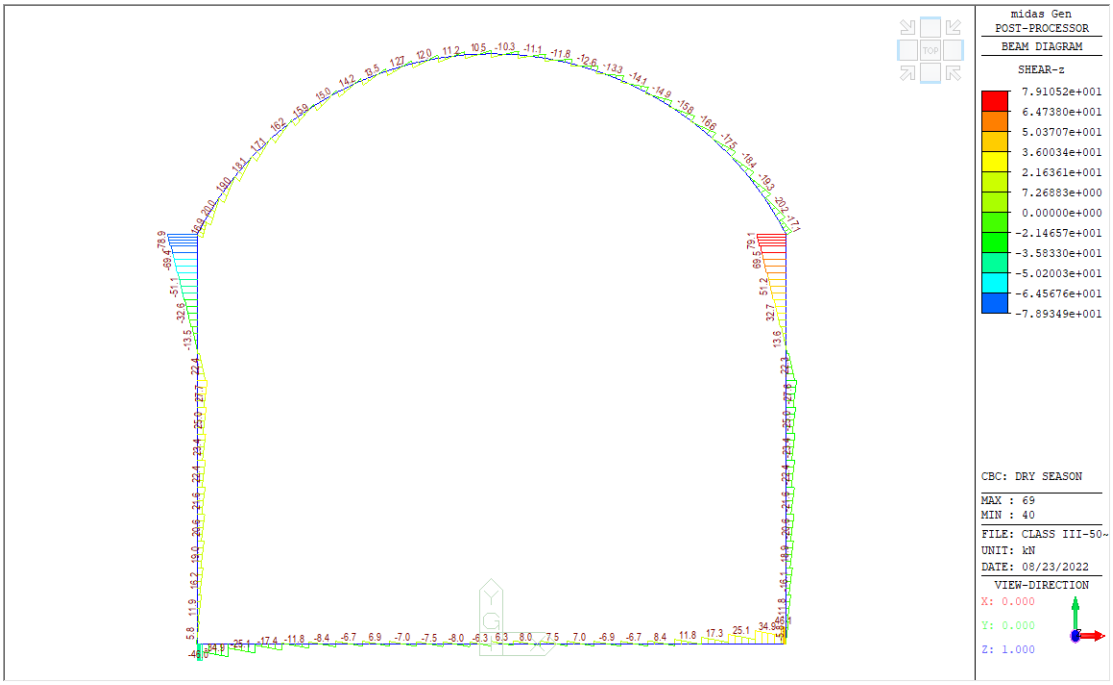


Figure 4.1.1-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.2 Figure of internal forces of concrete lining (Chainage 0+195.039)

The concrete lining from CH175.039 to CH195.039, class III, *concrete lining thickness 0.8m*, double-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

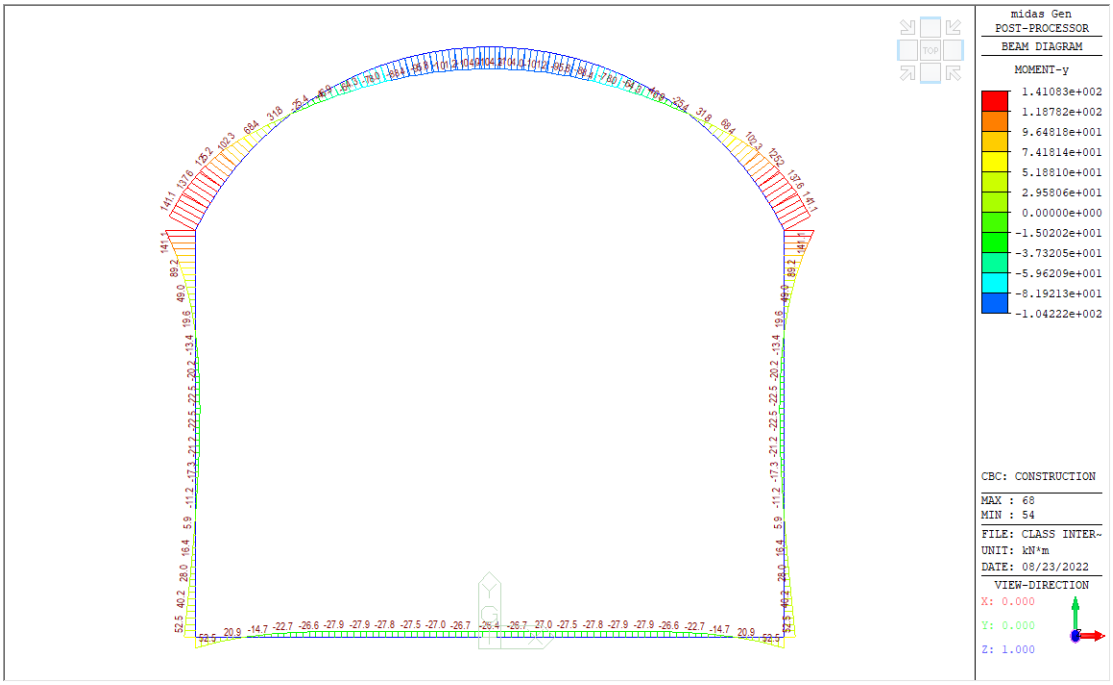


Figure 4.1.2-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

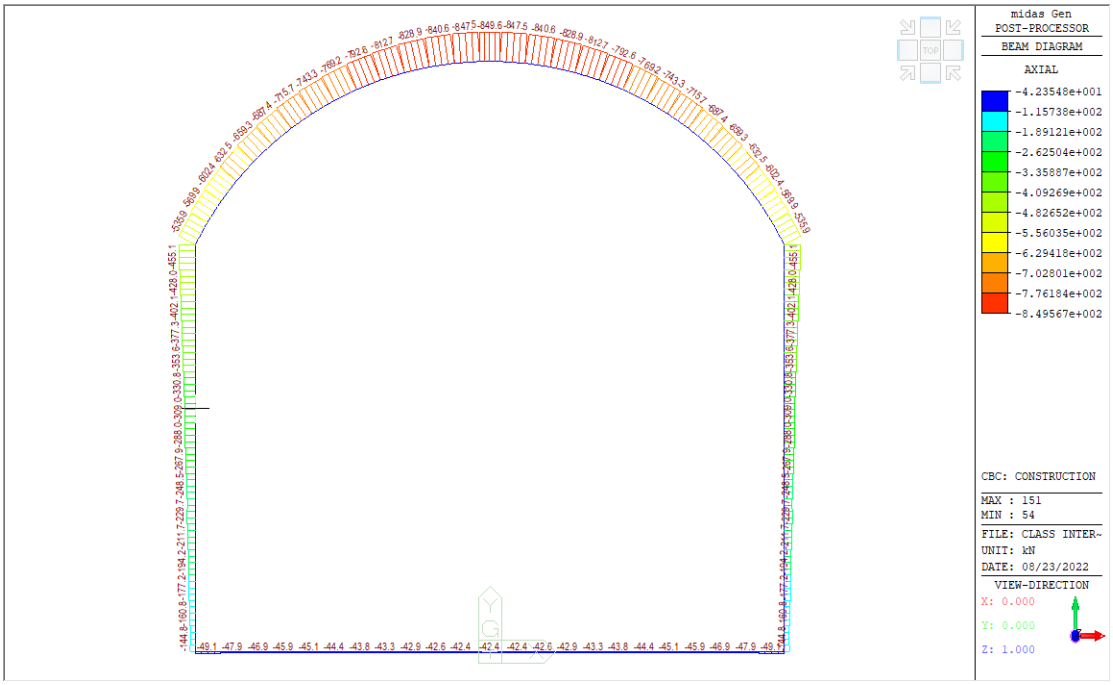


Figure 4.1.2-2 Figure of Axial Force at Concrete Lining Section (CASE1)

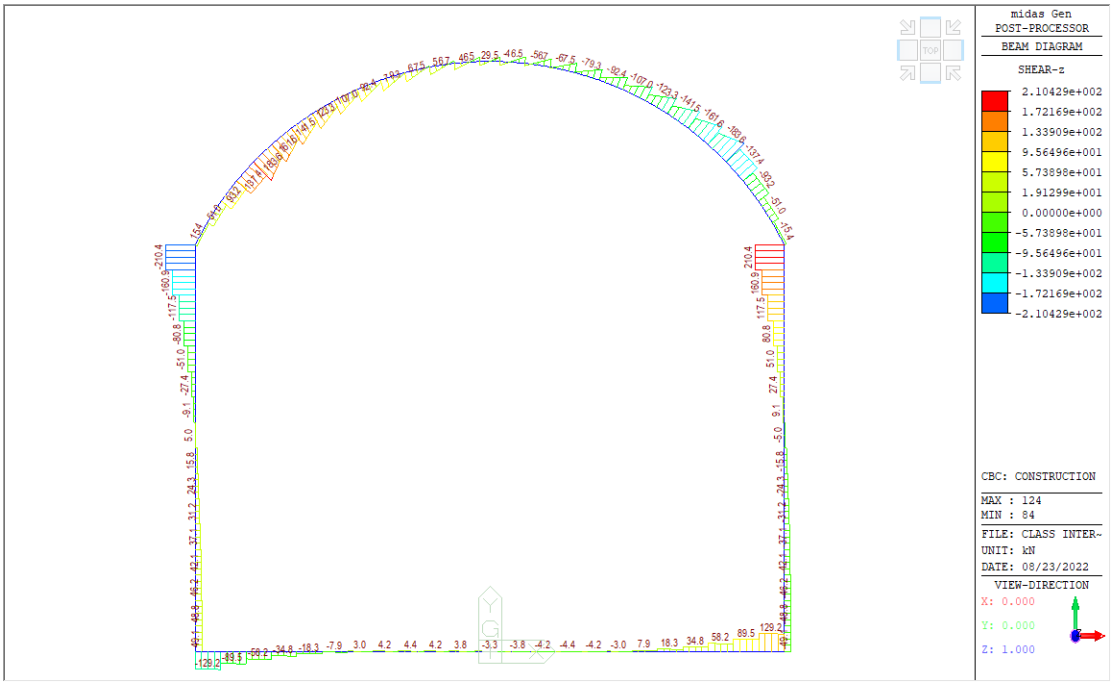


Figure 4.1.2-3 Figure of Shear Force at Concrete Lining Section (CASE1)

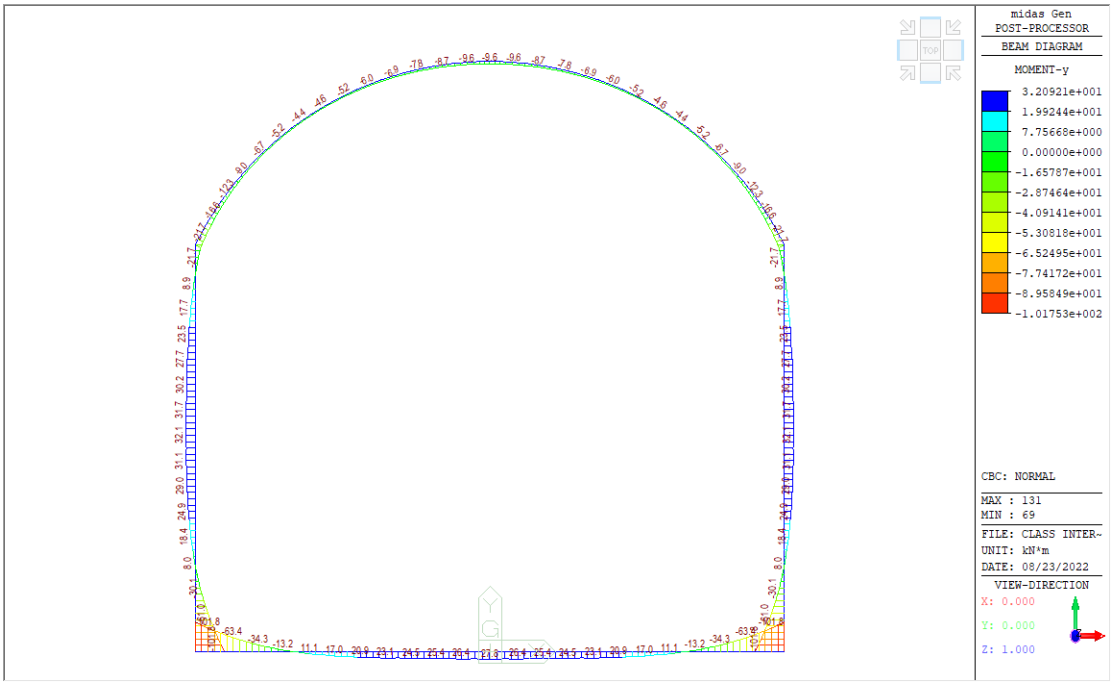


Figure 4.1.2-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

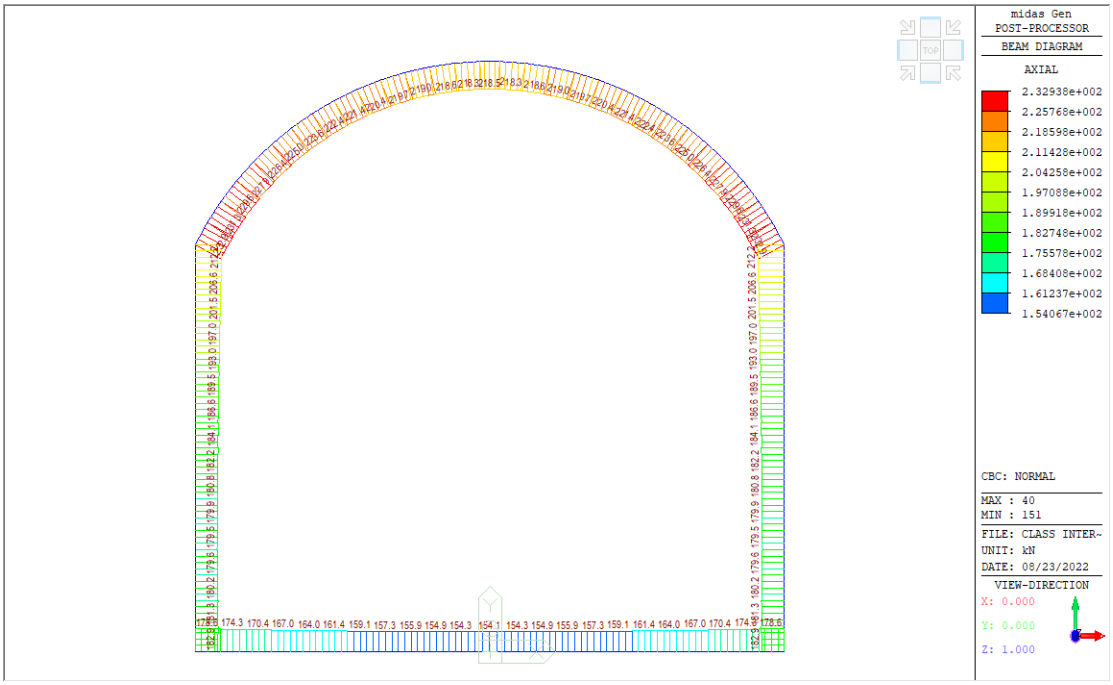


Figure 4.1.2-5 Figure of Axial Force at Concrete Lining Section (CASE2)

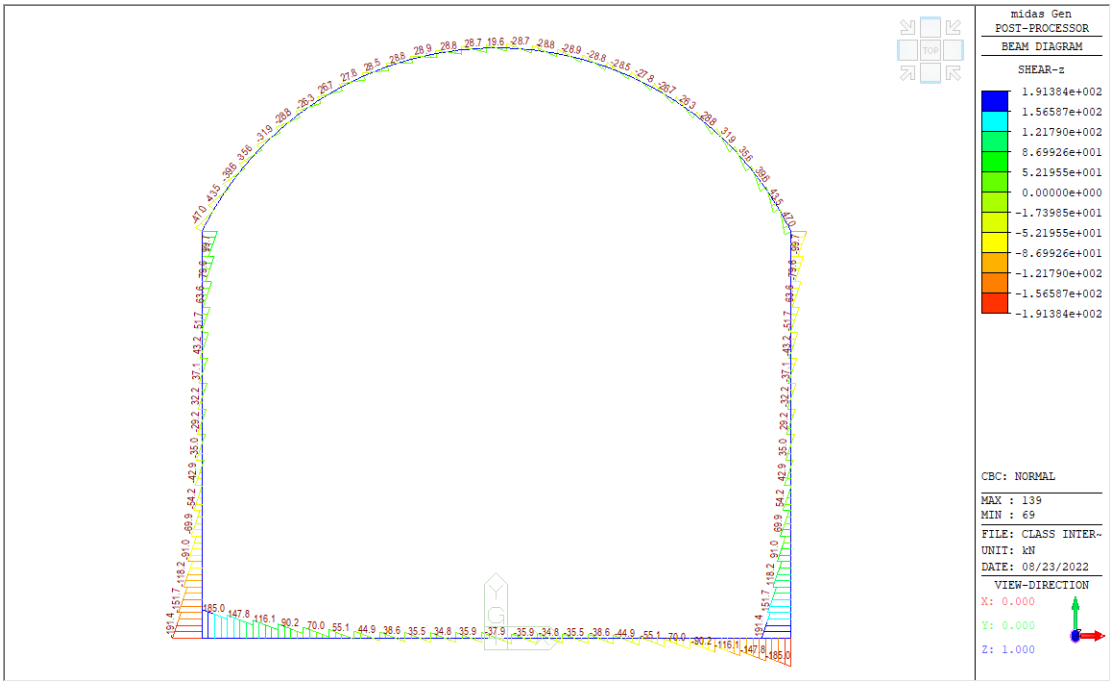


Figure 4.1.2-6 Figure of Shear Force at Concrete Lining Section (CASE2)

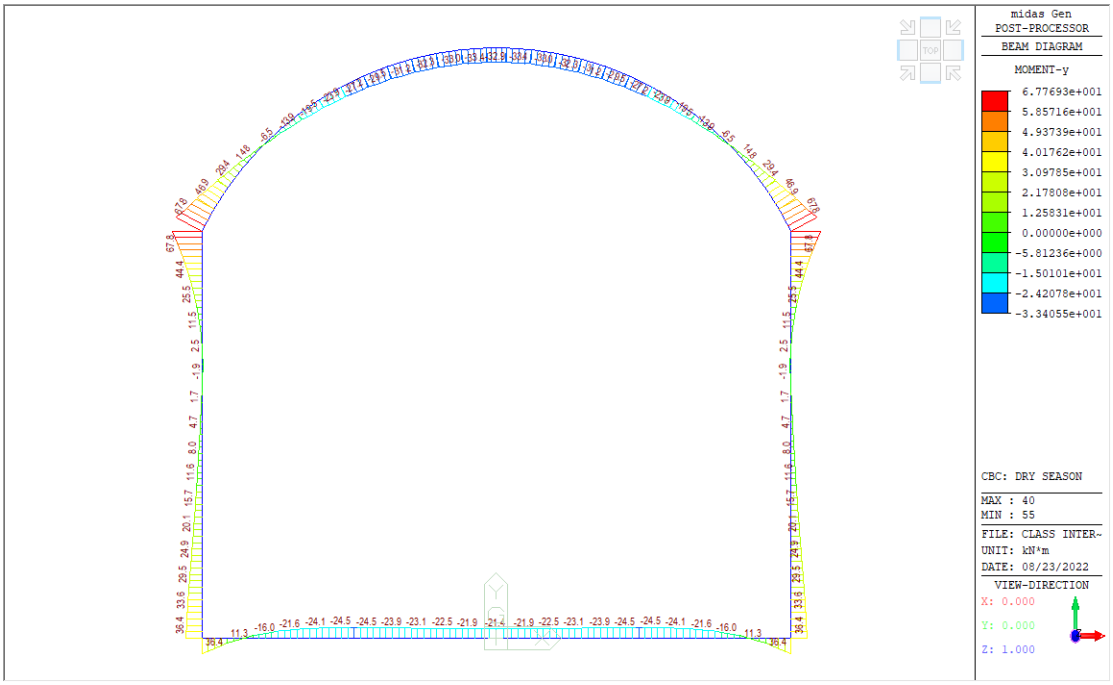


Figure 4.1.2-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

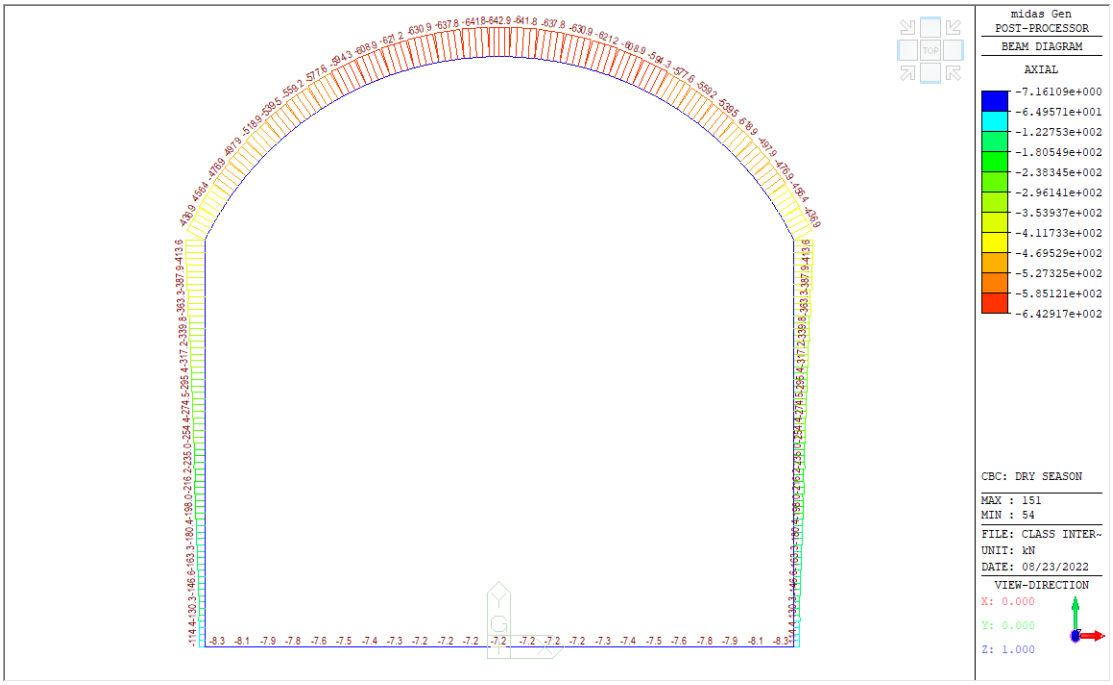


Figure 4.1.2-8 Figure of Axial Force at Concrete Lining Section (CASE3)

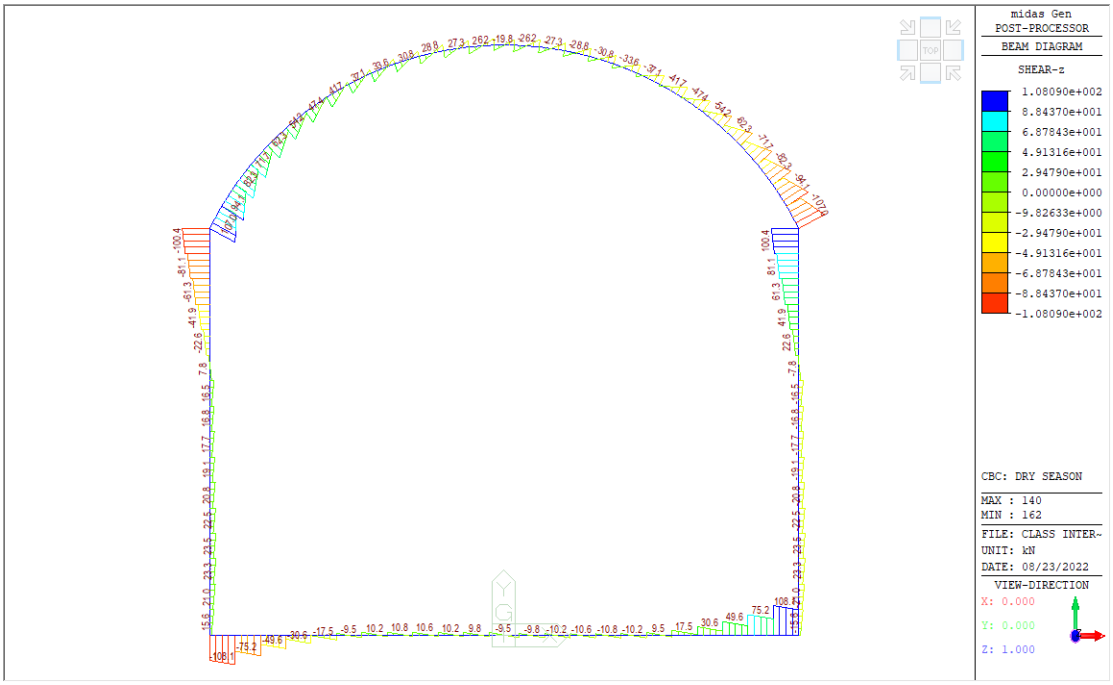


Figure 4.1.2-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.3 Figure of internal forces of concrete lining (Chainage 0+226.935)

The concrete lining from CH207.59 to CH226.935, class IV, *concrete lining thickness 0.5m*, double-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

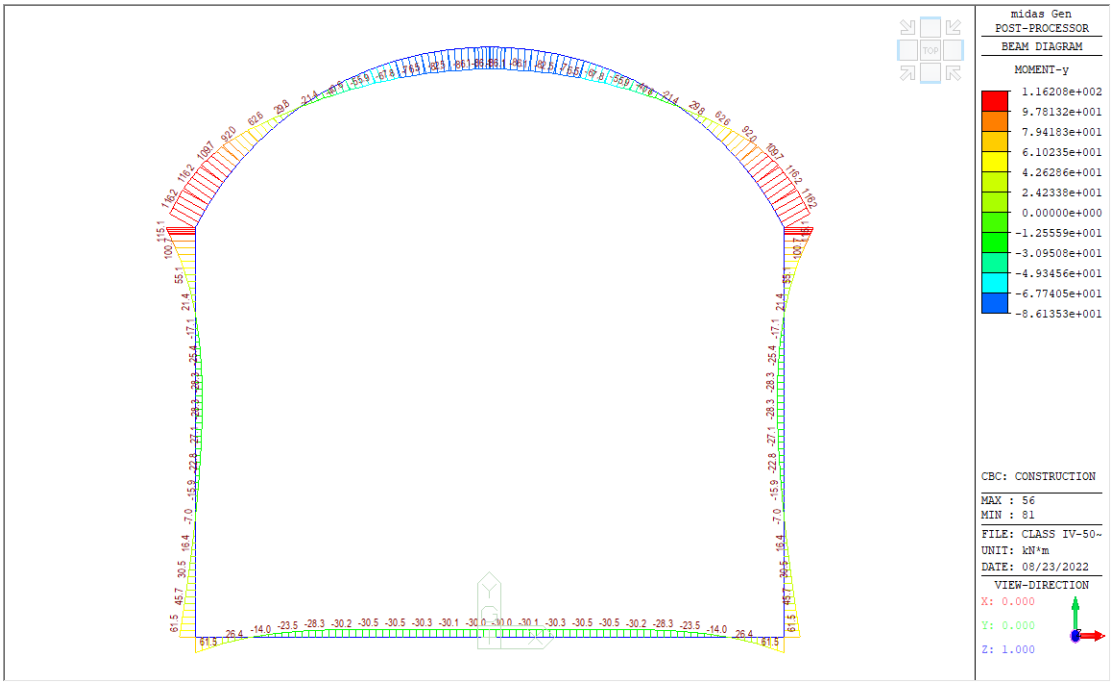


Figure 4.1.3-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

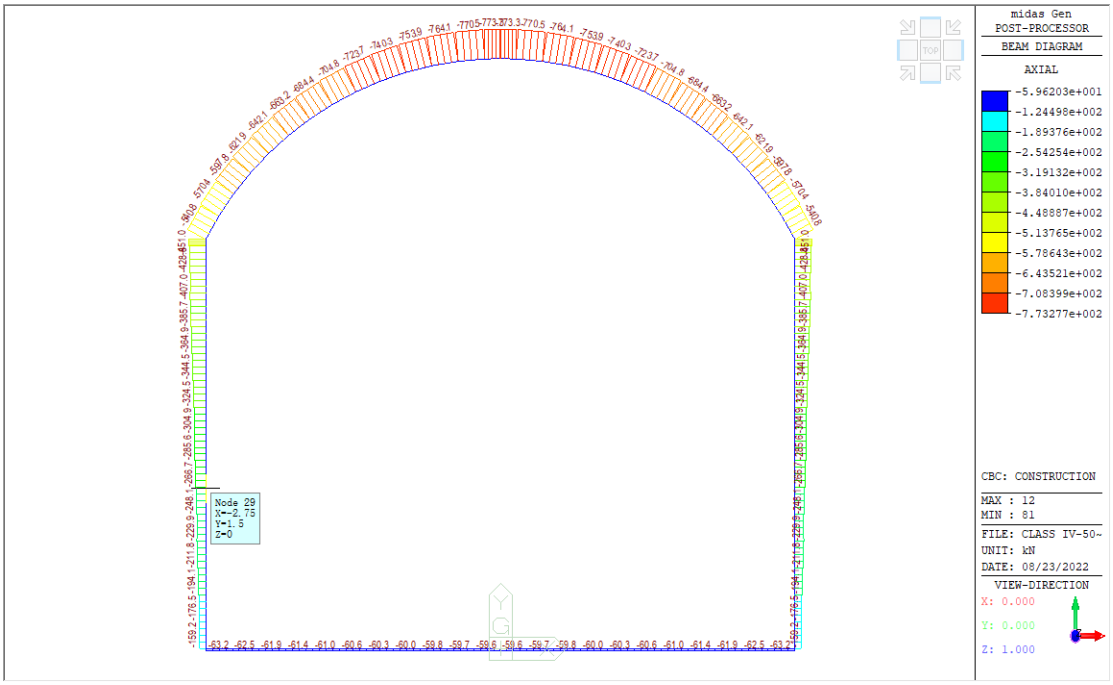


Figure 4.1.3-2 Figure of Axial Force at Concrete Lining Section (CASE1)

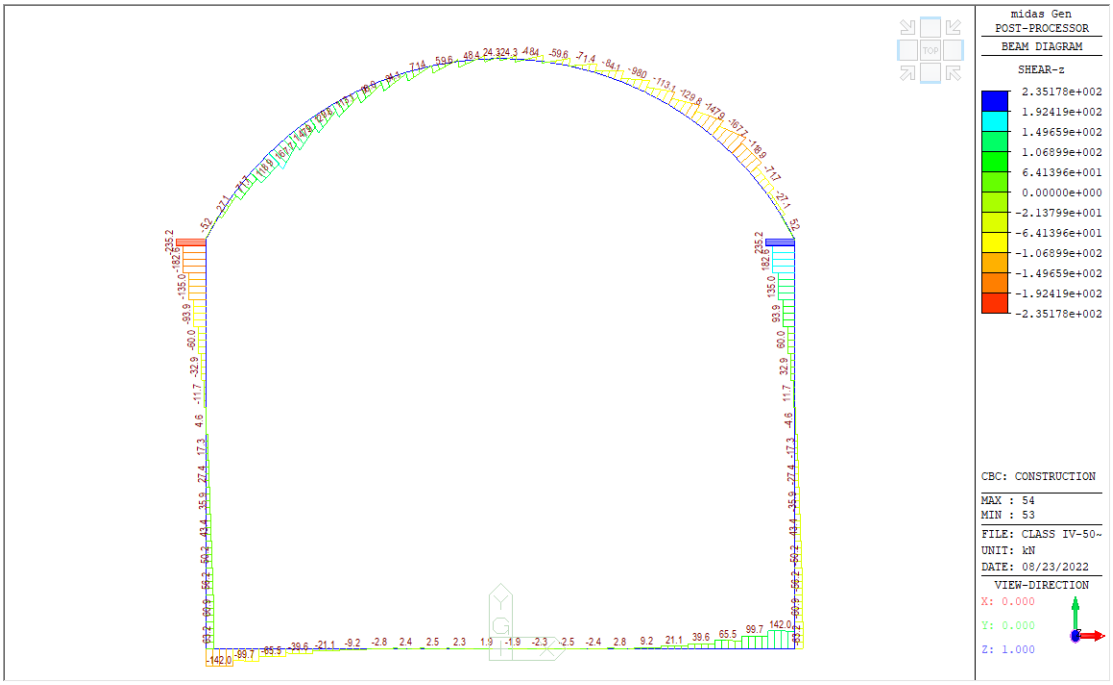


Figure 4.1.3-3 Figure of Shear Force at Concrete Lining Section (CASE1)

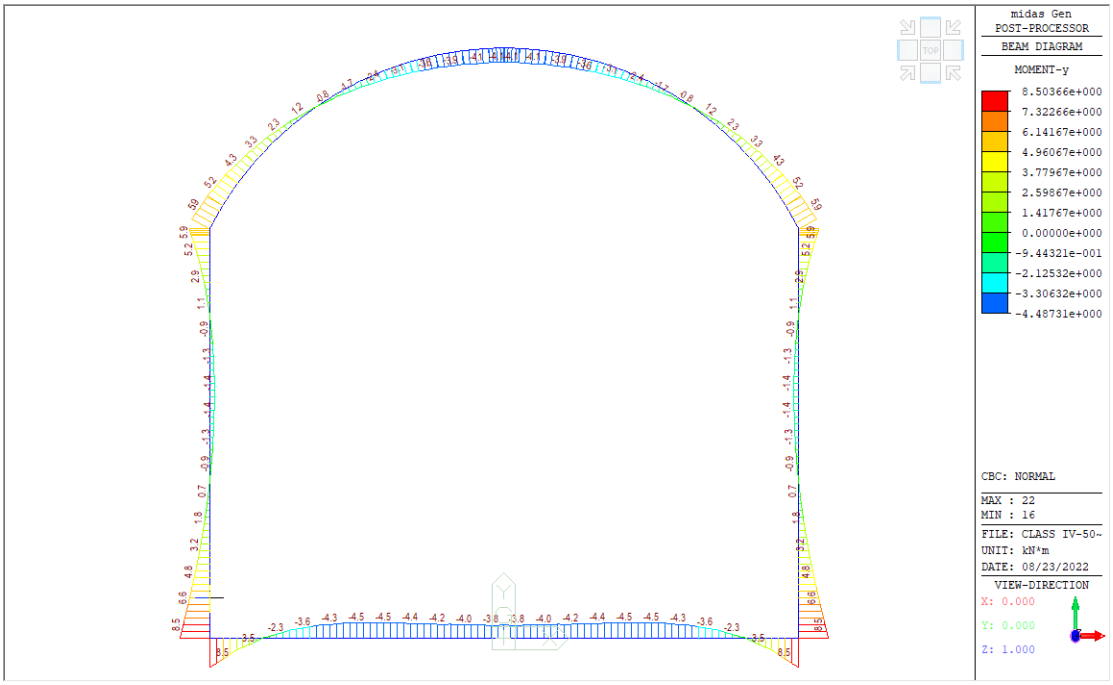


Figure 4.1.3-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

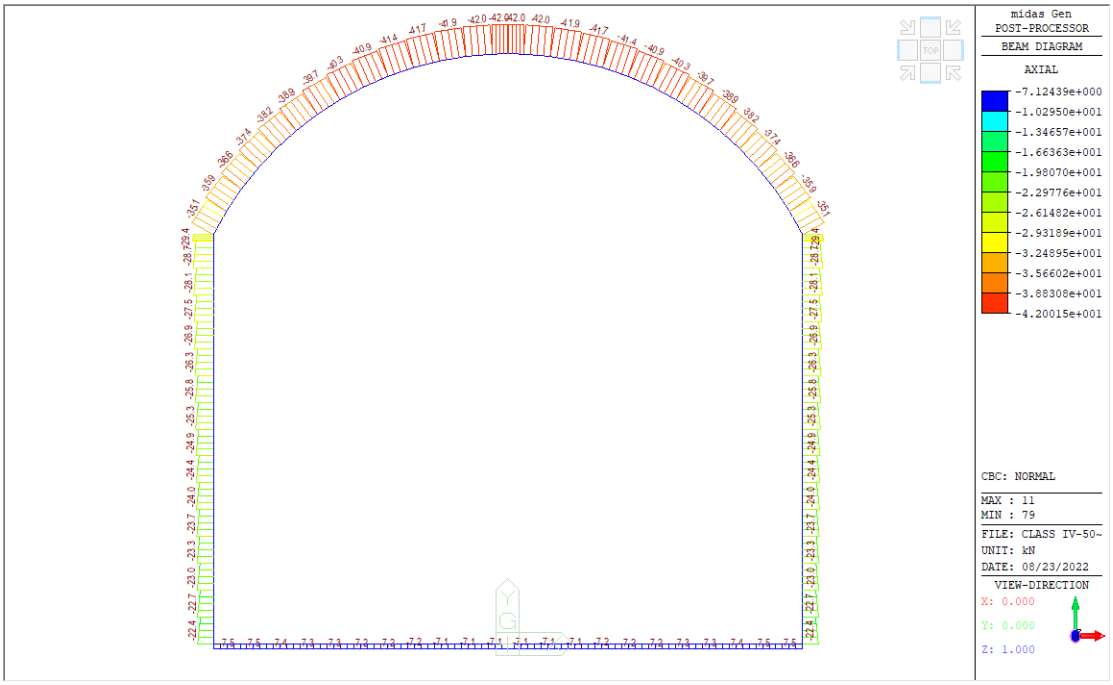


Figure 4.1.3-5 Figure of Axial Force at Concrete Lining Section (CASE2)

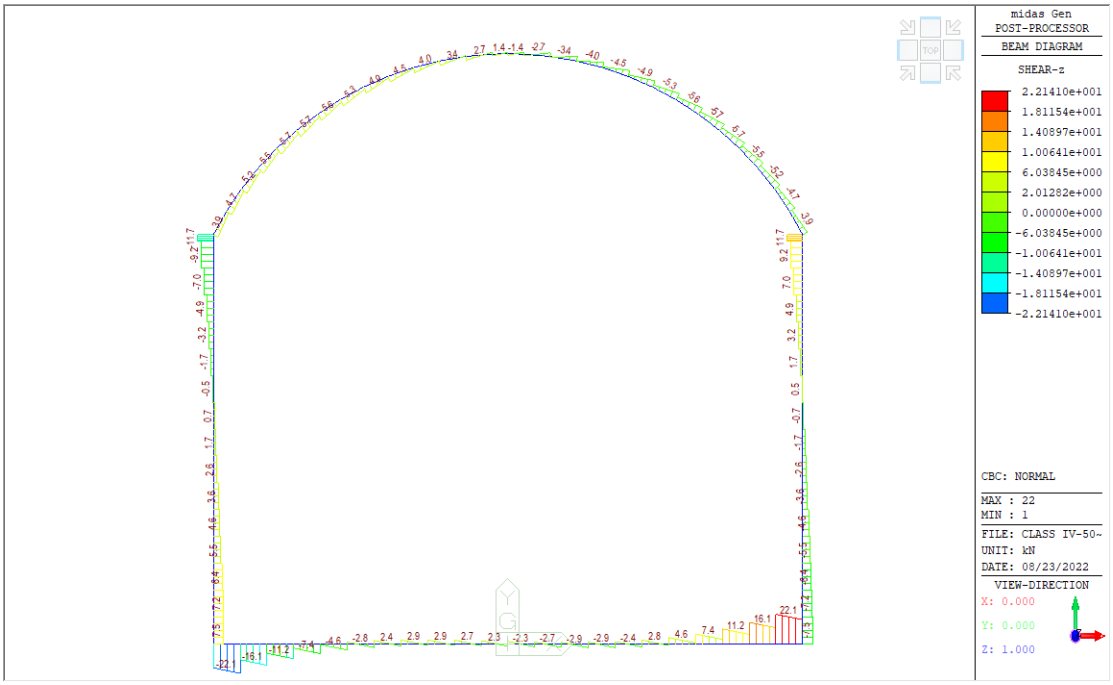


Figure 4.1.3-6 Figure of Shear Force at Concrete Lining Section (CASE2)

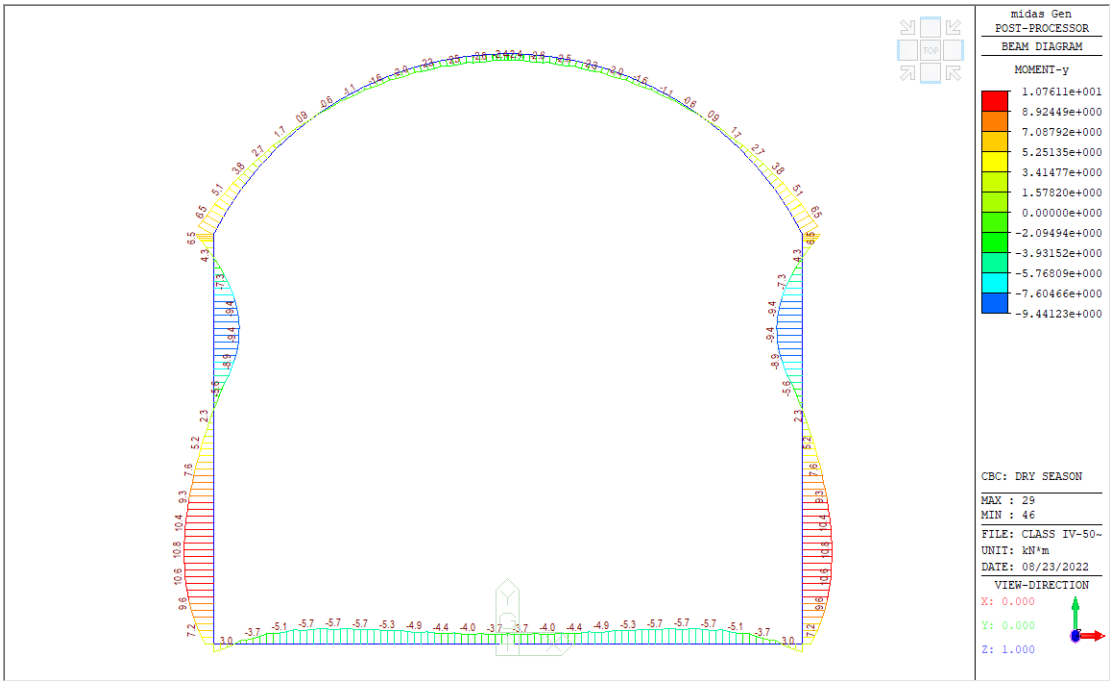


Figure 4.1.3-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

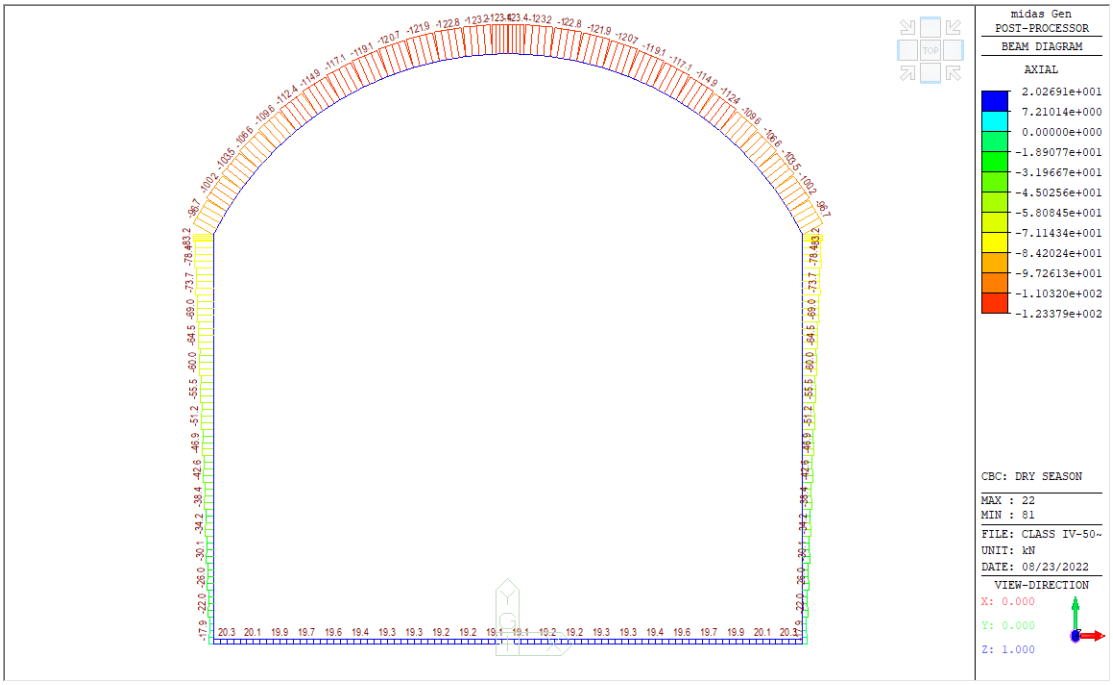


Figure 4.1.3-8 Figure of Axial Force at Concrete Lining Section (CASE3)

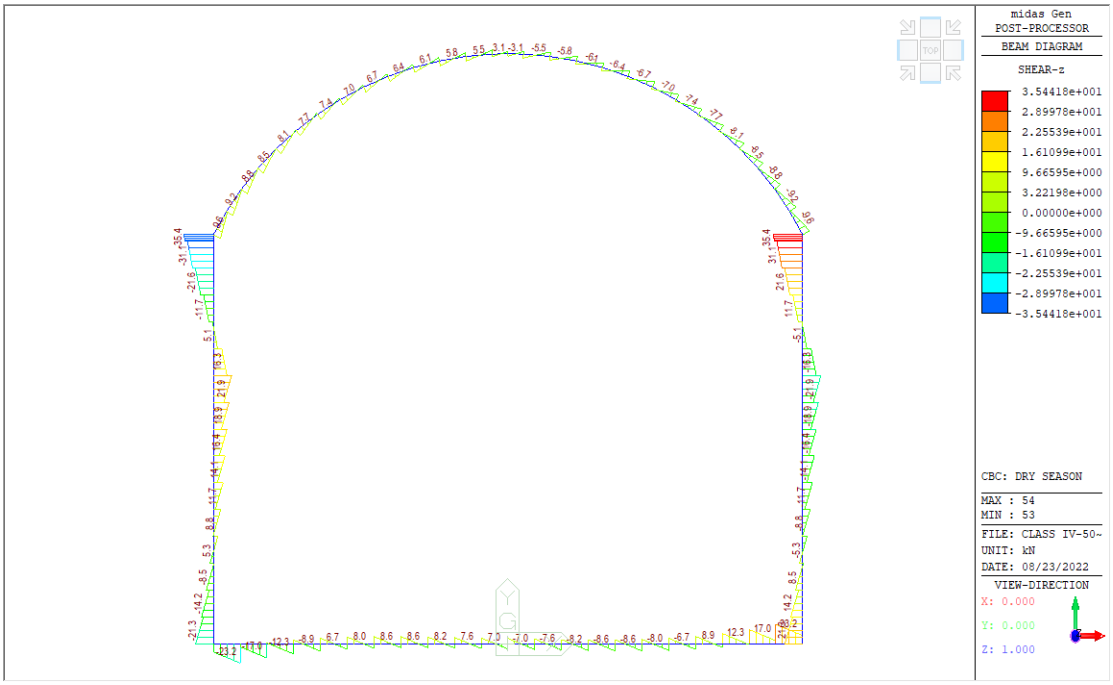


Figure 4.1.3-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.4 Figure of internal forces of concrete lining (Chainage 0+385.330)

The concrete lining from CH226.935 to CH385.330, class III, *concrete lining thickness 0.3m*, single-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

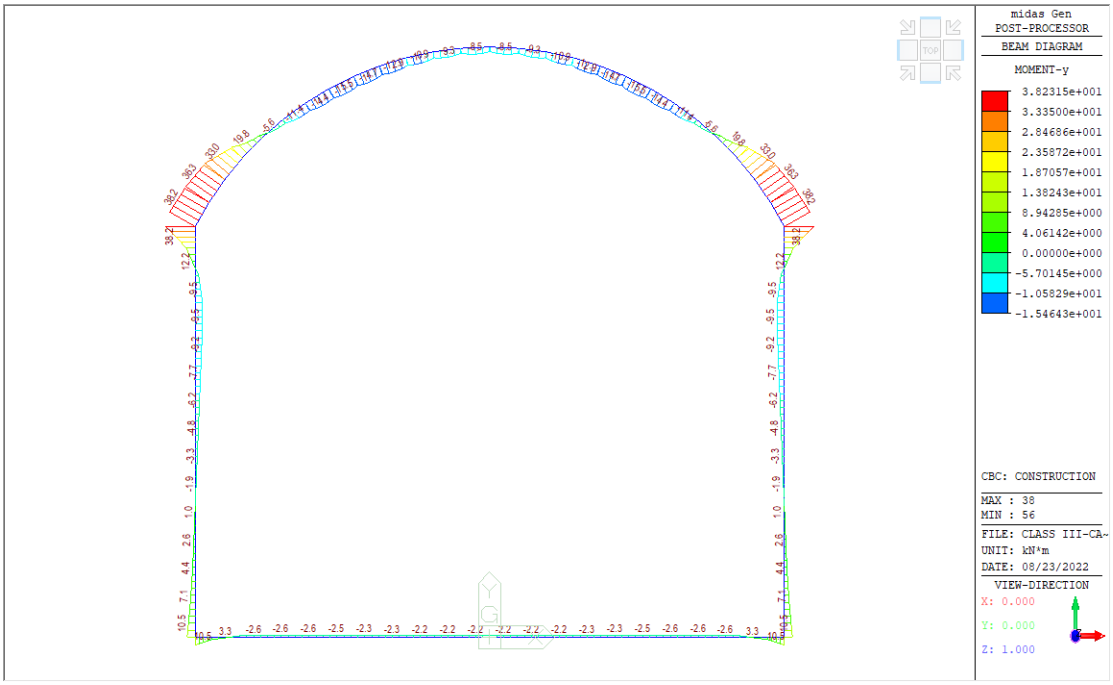


Figure 4.1.4-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

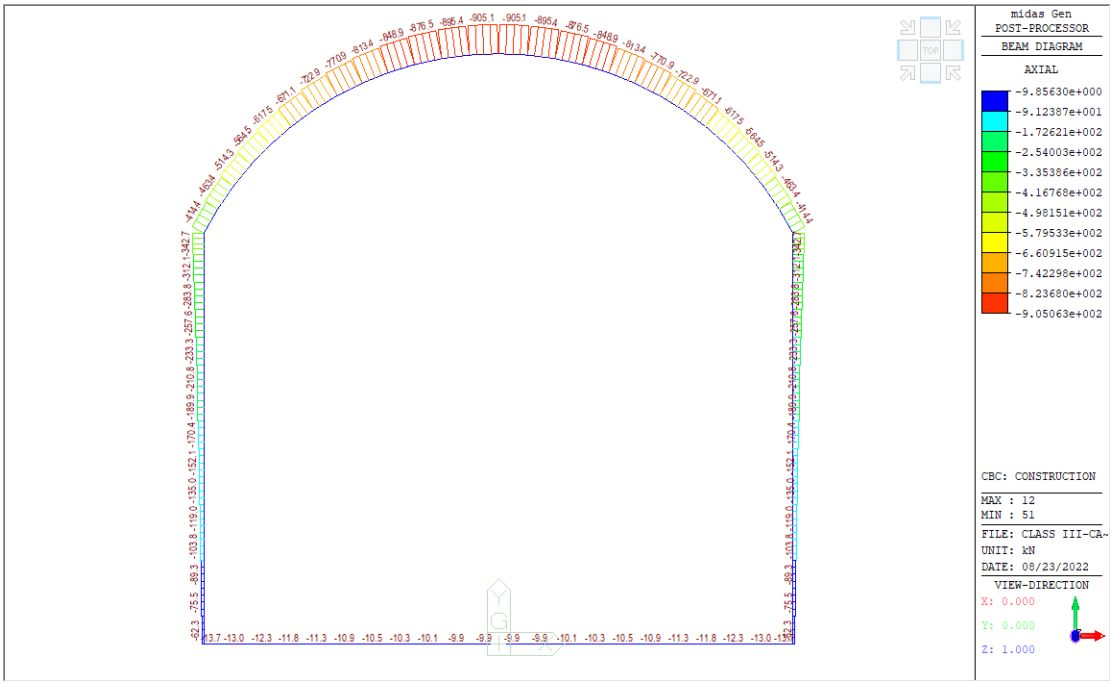


Figure 4.1.4-2 Figure of Axial Force at Concrete Lining Section (CASE1)

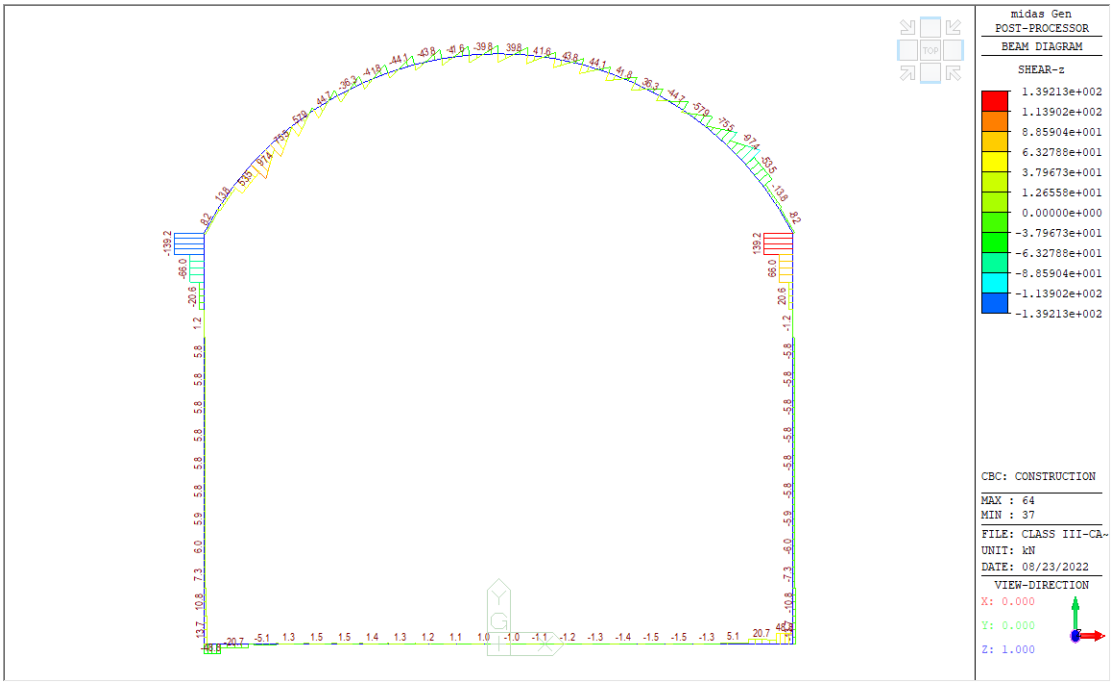


Figure 4.1.4-3 Figure of Shear Force at Concrete Lining Section (CASE1)

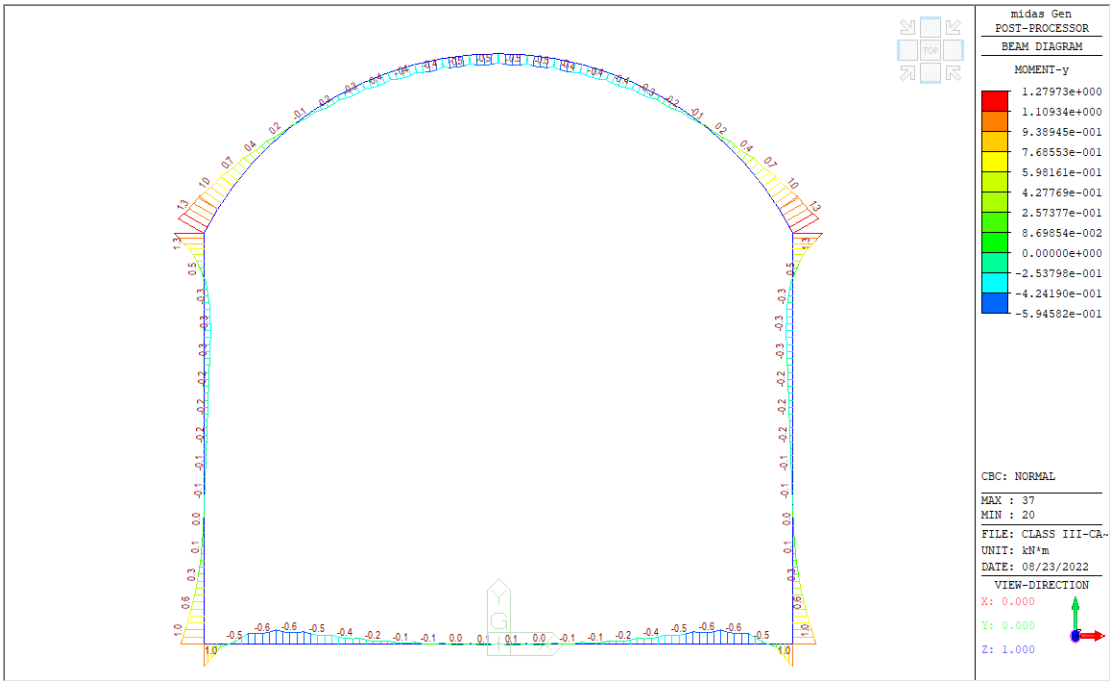


Figure 4.1.4-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

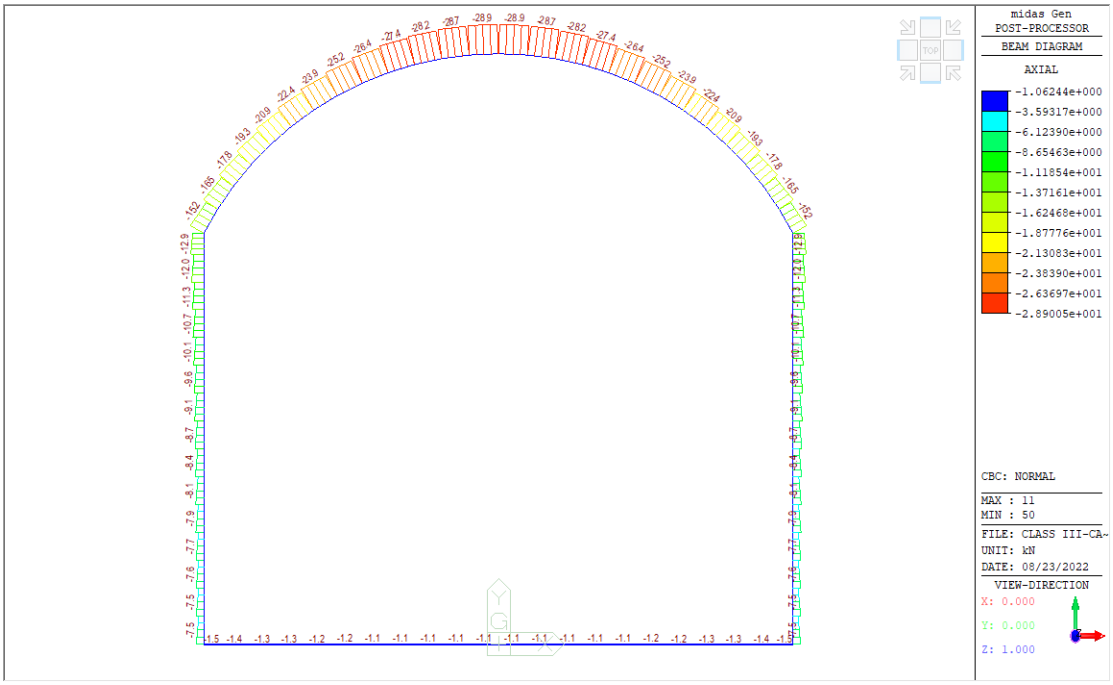


Figure 4.1.4-5 Figure of Axial Force at Concrete Lining Section (CASE2)

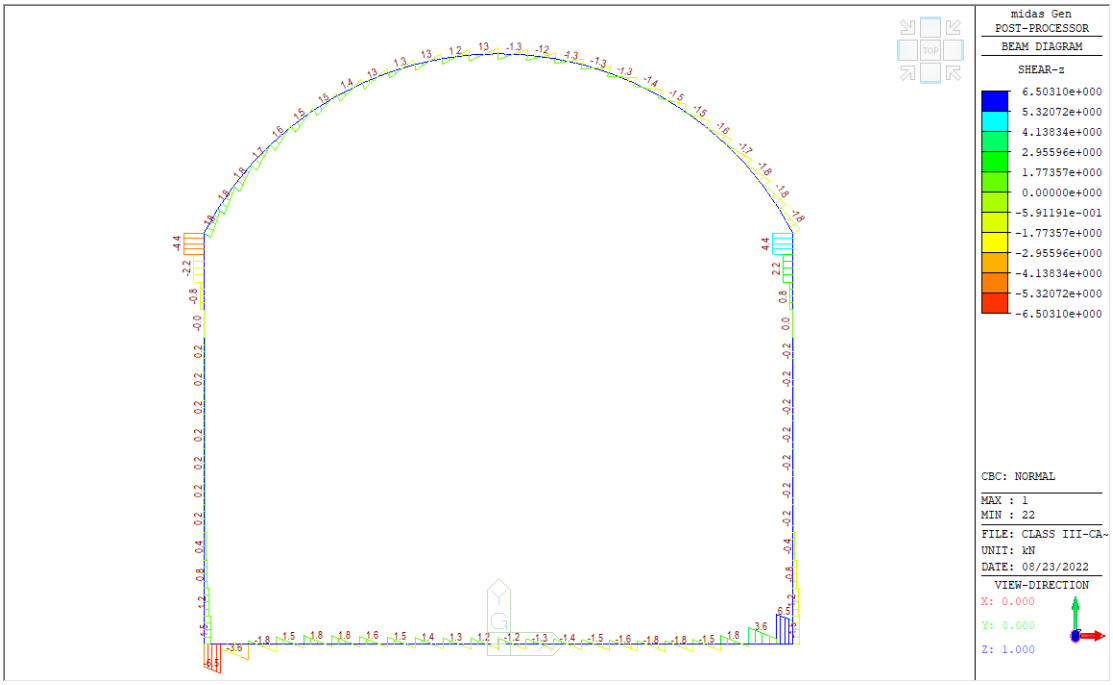


Figure 4.1.4-6 Figure of Shear Force at Concrete Lining Section (CASE2)

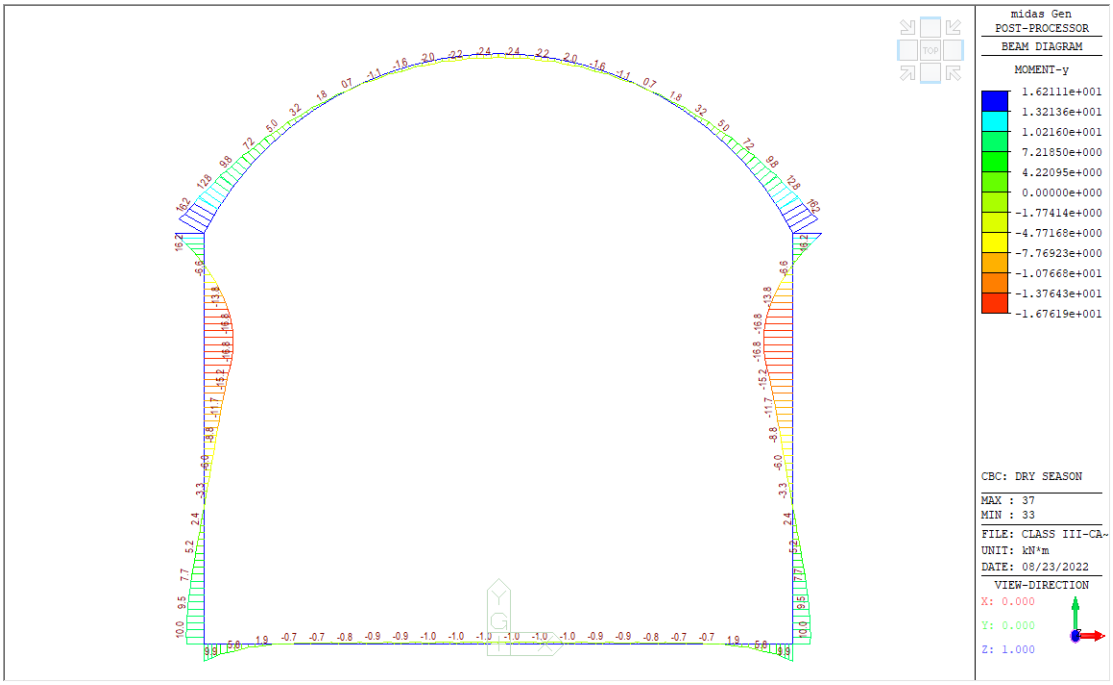


Figure 4.1.4-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

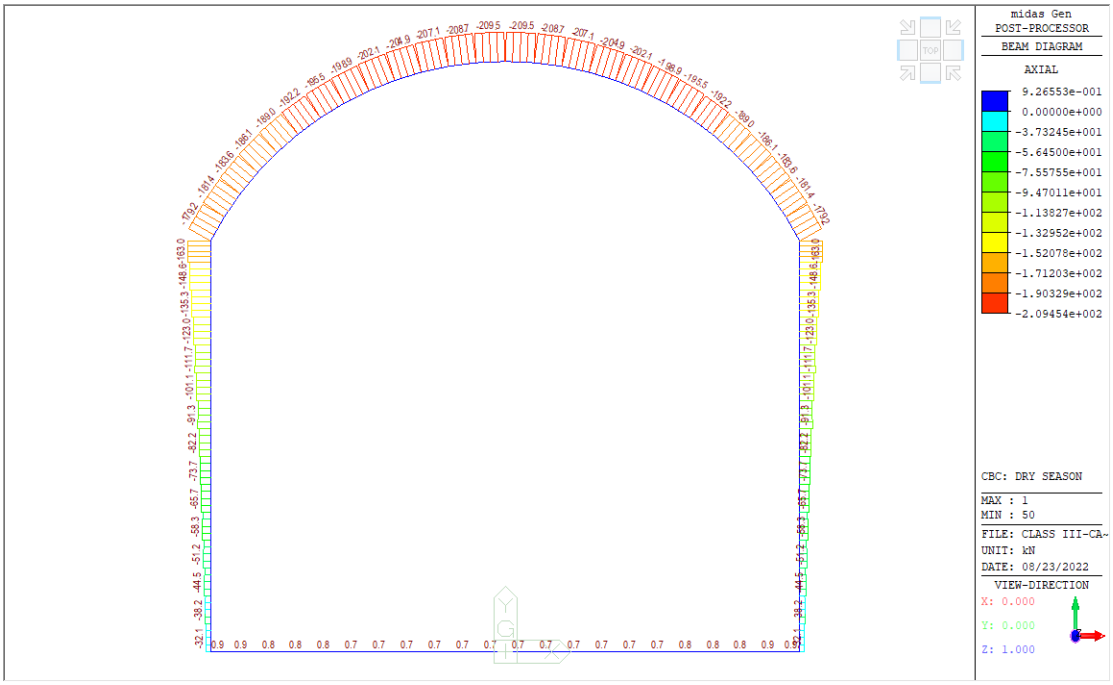


Figure 4.1.4-8 Figure of Axial Force at Concrete Lining Section (CASE3)

Figure 4.1.4-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.1.5 Figure of internal forces of concrete lining (Chainage 0+413.042)

The concrete lining from CH385.330 to CH413.042, class III, *concrete lining thickness 0.5m*, Double-sided reinforcement. The bending moment, axial force, shear force and the critical cases internal force diagrams are shown as follows.

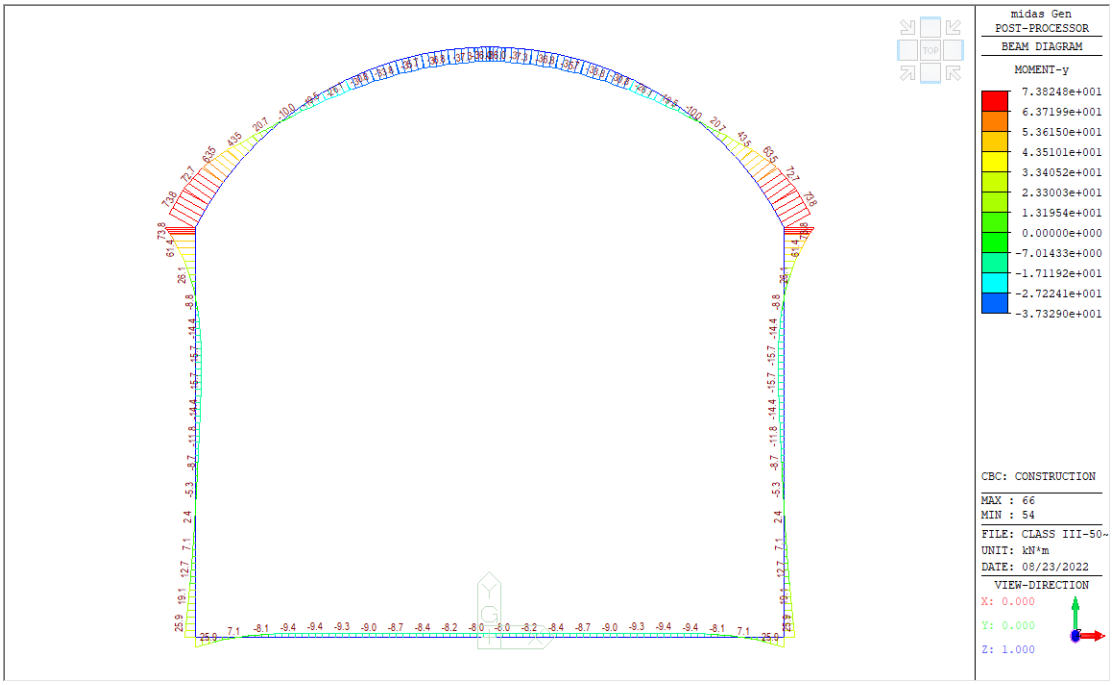


Figure 4.1.5-1 Figure of Bending Moment at Concrete Lining Section (CASE1)

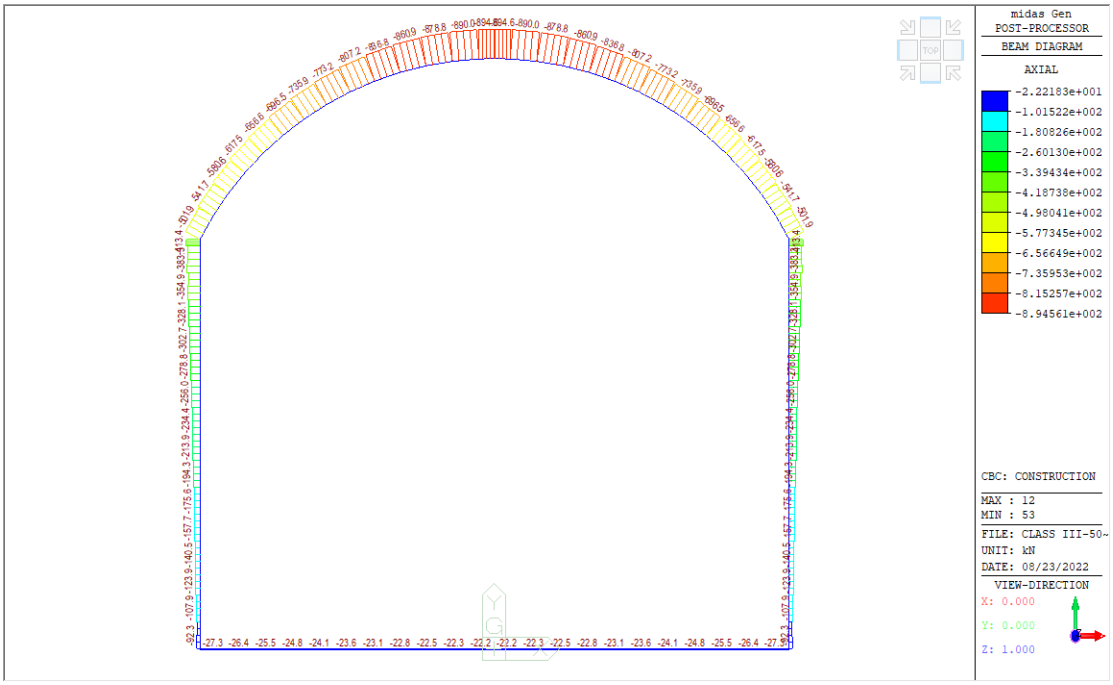


Figure 4.1.5-2 Figure of Axial Force at Concrete Lining Section (CASE1)

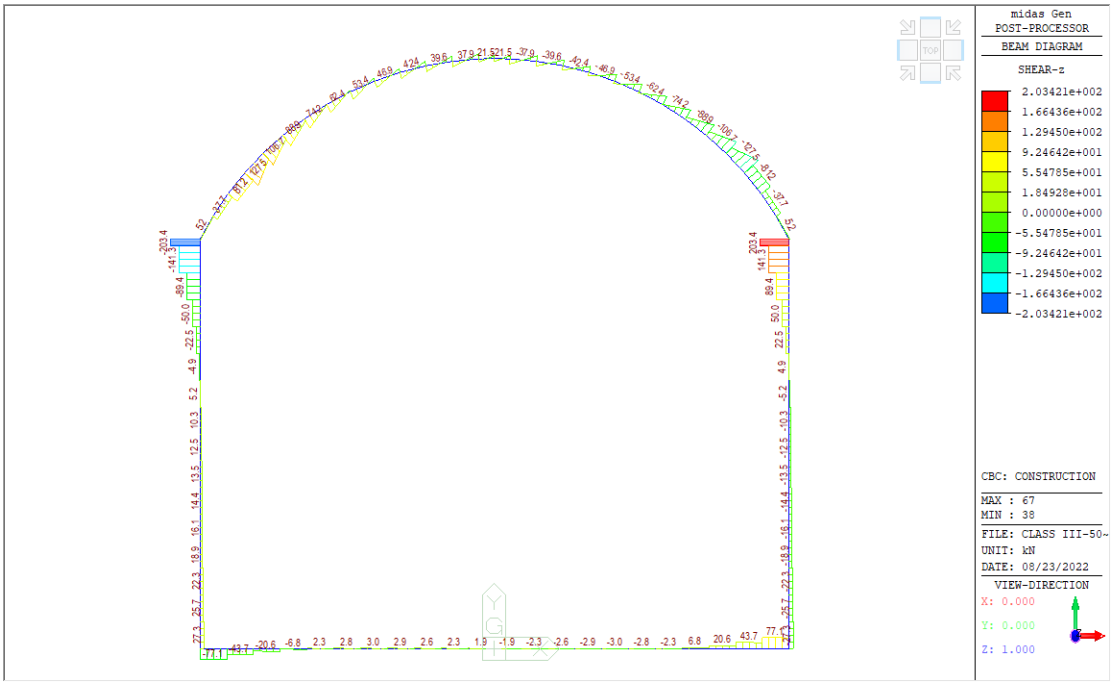


Figure 4.1.5-3 Figure of Shear Force at Concrete Lining Section (CASE1)

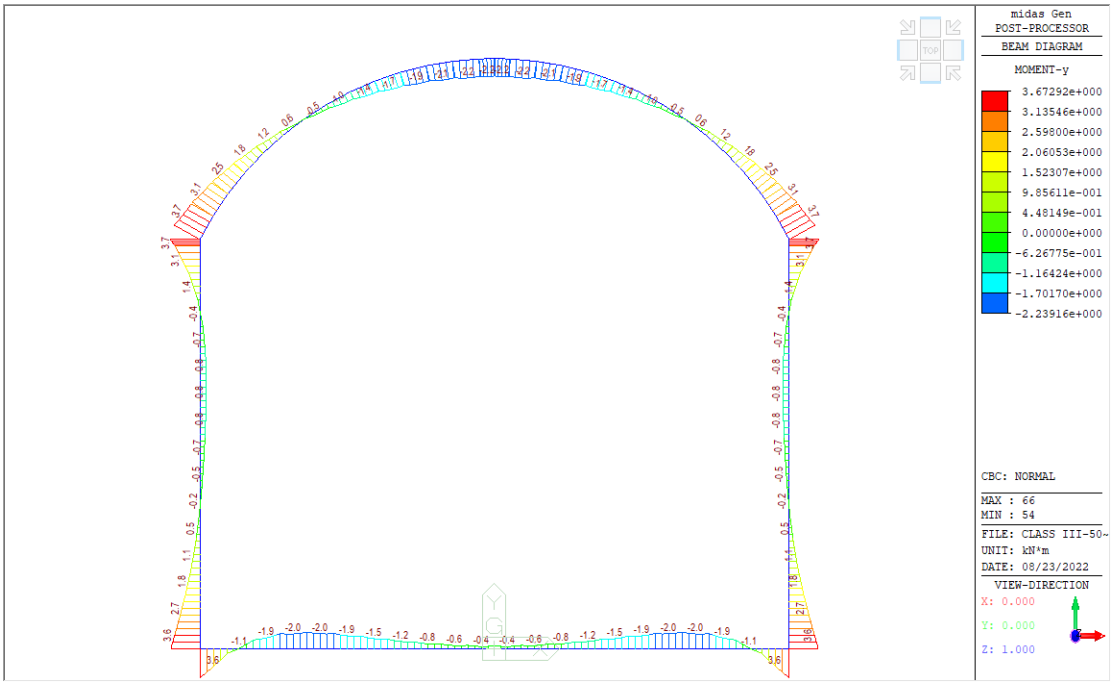


Figure 4.1.5-4 Figure of Bending Moment at Concrete Lining Section (CASE2)

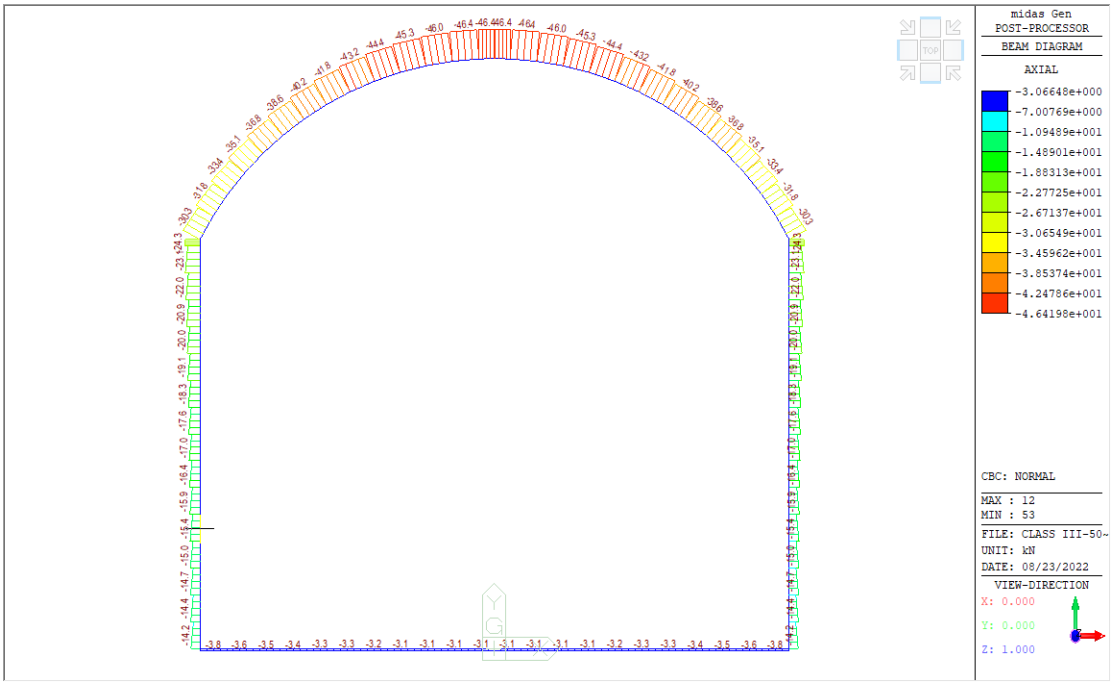


Figure 4.1.5-5 Figure of Axial Force at Concrete Lining Section (CASE2)

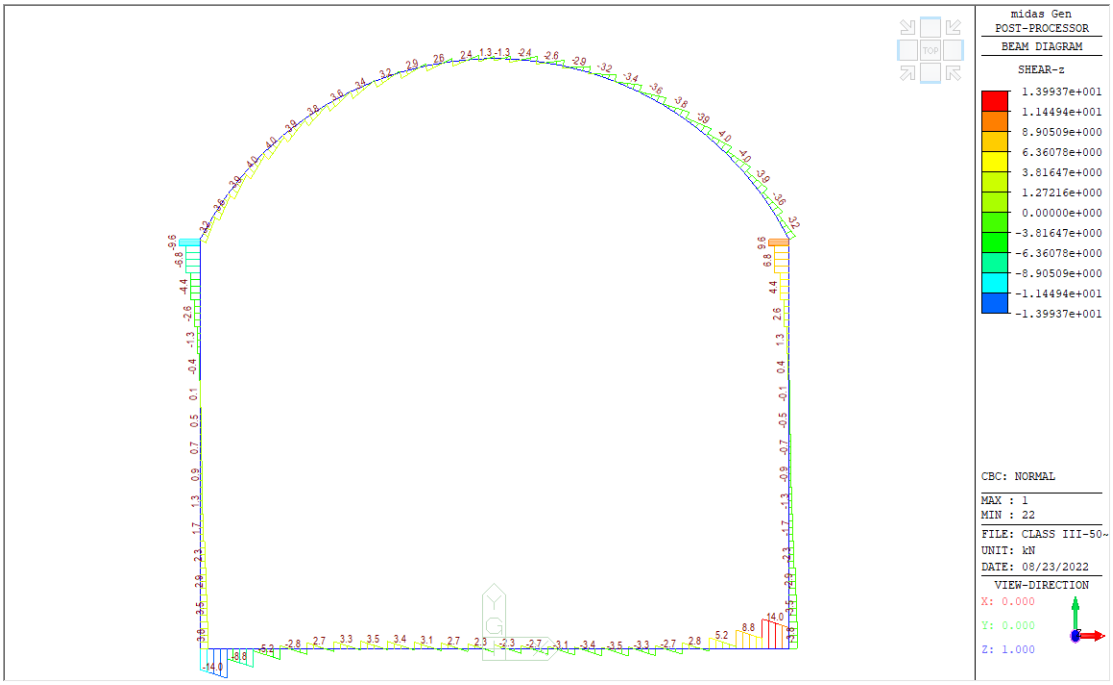


Figure 4.1.5-6 Figure of Shear Force at Concrete Lining Section (CASE2)

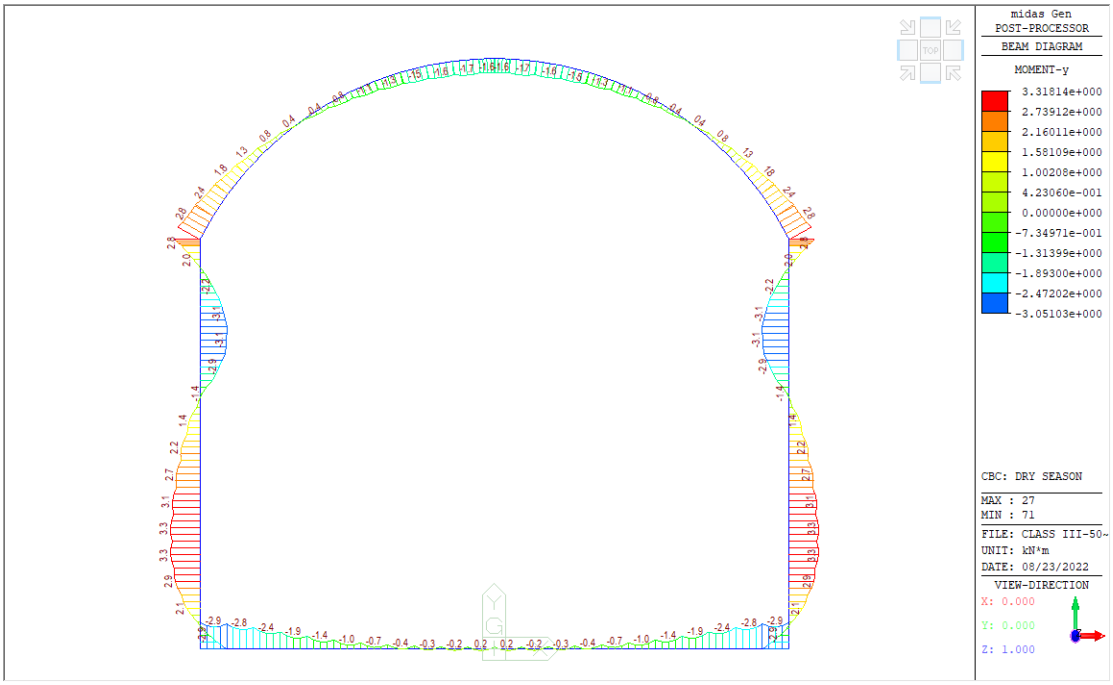


Figure 4.1.5-7 Figure of Bending Moment at Concrete Lining Section (CASE3)

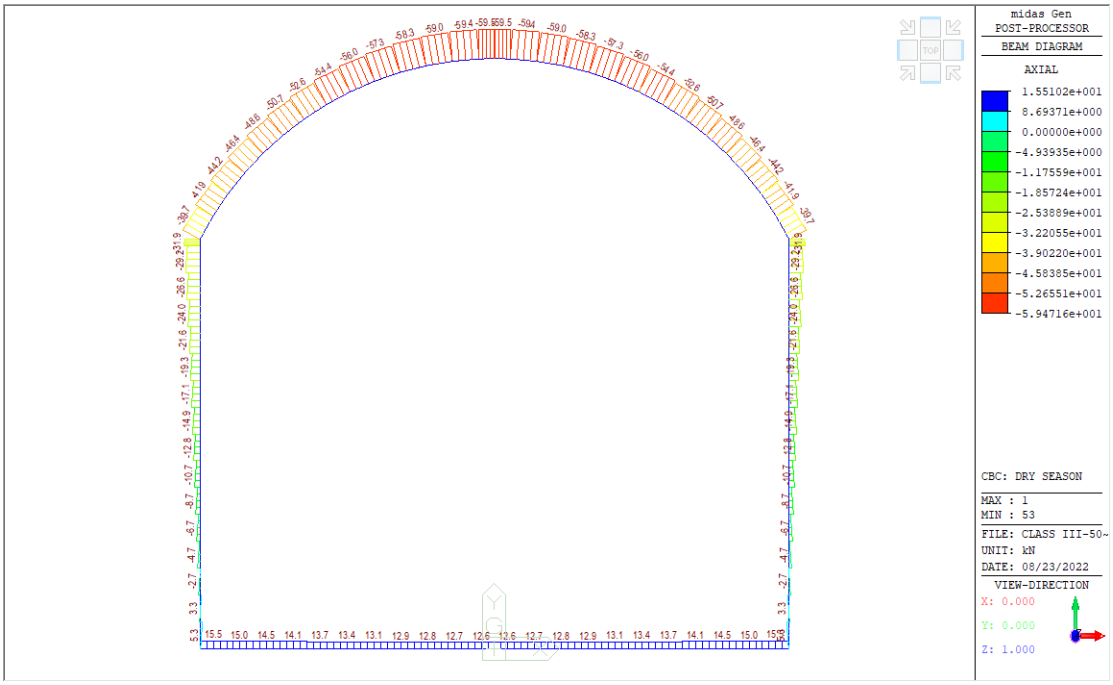


Figure 4.1.5-8 Figure of Axial Force at Concrete Lining Section (CASE3)

Figure 4.1.5-9 Figure of Shear Force at Concrete Lining Section (CASE3)

4.2 Reinforcement Calculation

The double sided reinforcing for concrete lining is carried out by Midas Gen, and the single sided reinforcing is in line with the requirement of formula of ACI 318-19, the calculating results are as follows in addition.

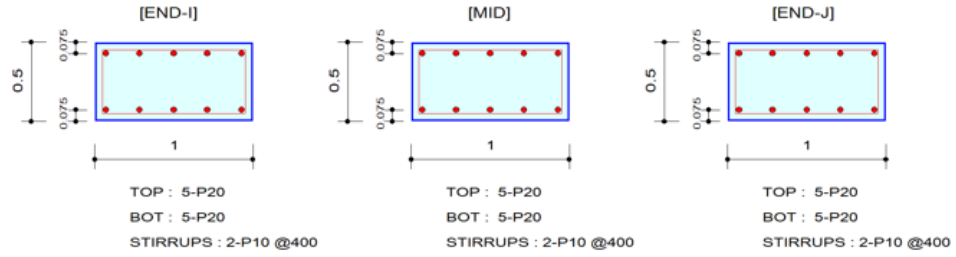
4.2.1 Figure of reinforcement of concrete lining (Chainage 0+020.00)

The concrete lining thickness is 0.5m.

1. Design Information

Design Code	: ACI318M-14	Unit System	: kN, m
Material Data	: fc = 24000, fy = 500000, fys = 500000 KPa		
Section Property	: 1X0.5 (No : 1)	Beam Span	: 0.252575 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	2	2	2
Moment (Mu)	51.82	50.41	51.82
Factored Strength (PhiMn)	286.81	286.81	286.81
Check Ratio (Mu/PhiMn)	0.1807	0.1758	0.1807
(+) Load Combination No.	1	1	1
Moment (Mu)	70.36	70.28	70.36
Factored Strength (PhiMn)	286.81	286.81	286.81
Check Ratio (Mu/PhiMn)	0.2453	0.2450	0.2453
Using Rebar Top (As_top)	0.0016	0.0016	0.0016
Using Rebar Bot (As_bot)	0.0016	0.0016	0.0016

4.2.2 Figure of reinforcement of concrete lining (Chainage 0+195.039)

The concrete lining thickness is 0.8m.

Reinforcement of invert of CH 195.039

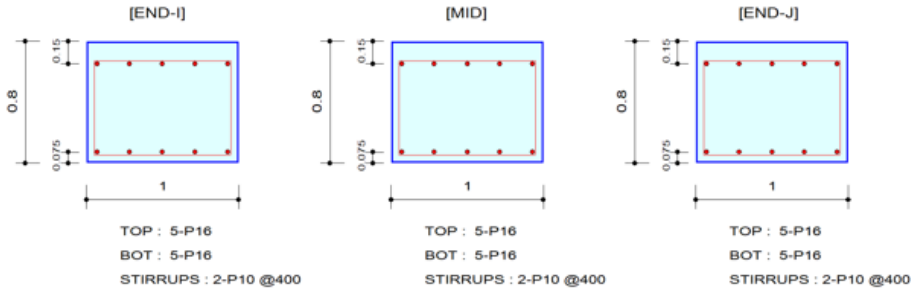
1. Design Information

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 30000, fy = 500000, fys = 500000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.3 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	2	2	2
Moment (Mu)	101.75	90.69	101.75
Factored Strength (PhiMn)	289.59	289.59	289.59
Check Ratio (Mu/PhiMn)	0.3514	0.3132	0.3514
(+) Load Combination No.	1	1	1
Moment (Mu)	52.45	44.68	52.45
Factored Strength (PhiMn)	323.52	323.52	323.52
Check Ratio (Mu/PhiMn)	0.1621	0.1381	0.1621
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

Reinforcement of side wall and roof of CH 195.039

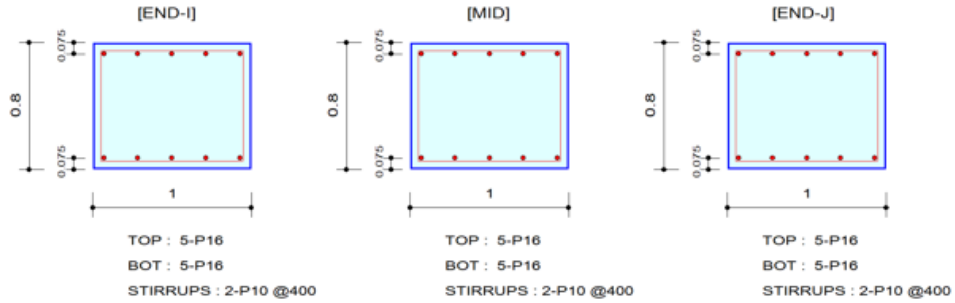
1. Design Information

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 500000 KPa

Section Property: 1X0.8 (No : 1) Beam Span : 0.25 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	104.00	104.22	104.00
Factored Strength (PhiMn)	322.41	322.41	322.41
Check Ratio (Mu/PhiMn)	0.3226	0.3233	0.3226
(+) Load Combination No.	1	1	1
Moment (Mu)	141.08	140.14	141.08
Factored Strength (PhiMn)	322.41	322.41	322.41
Check Ratio (Mu/PhiMn)	0.4376	0.4347	0.4376
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4.2.3 Figure of reinforcement of concrete lining (Chainage 0+226.935)

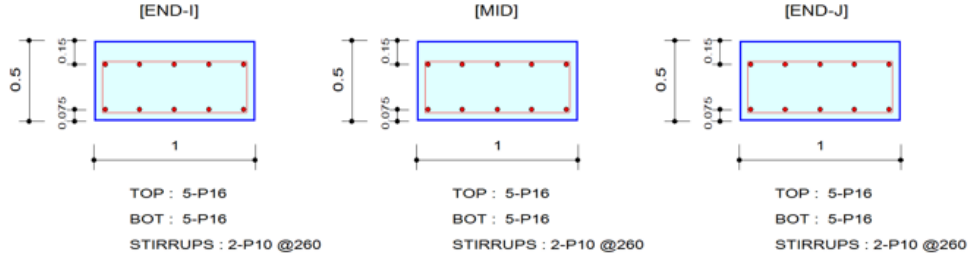
The concrete lining thickness is 0.5m.

Reinforcement of invert of CH 226.935

1. Design Information

Design Code	: ACI318M-14	Unit System	: kN, m
Material Data	: fc = 30000, fy = 500000, fys = 500000 KPa		
Section Property	: 1X0.5 (No : 1)	Beam Span	: 0.25 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	30.48	30.35	30.48
Factored Strength (PhiMn)	153.88	153.88	153.88
Check Ratio (Mu/PhiMn)	0.1981	0.1972	0.1981
(+) Load Combination No.	1	1	1
Moment (Mu)	61.49	52.80	61.49
Factored Strength (PhiMn)	187.80	187.80	187.80
Check Ratio (Mu/PhiMn)	0.3274	0.2811	0.3274
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

Reinforcement of side wall and roof of CH 226.935

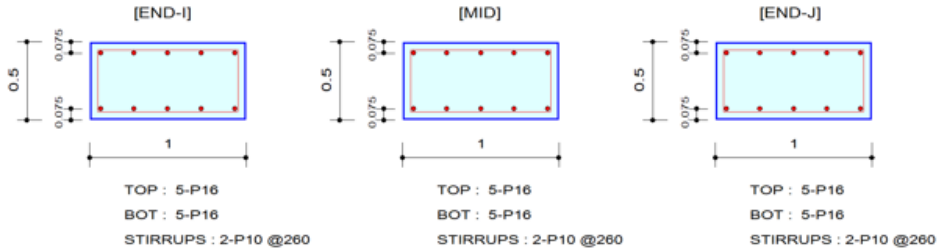
1. Design Information

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 500000 KPa

Section Property: 1X0.5 (No : 1) Beam Span : 0.25 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	86.13	86.14	86.13
Factored Strength (PhiMn)	186.69	186.69	186.69
Check Ratio (Mu/PhiMn)	0.4614	0.4614	0.4614
(+) Load Combination No.	1	1	1
Moment (Mu)	116.21	115.90	116.21
Factored Strength (PhiMn)	186.69	186.69	186.69
Check Ratio (Mu/PhiMn)	0.6225	0.6208	0.6225
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4.2.4 Figure of reinforcement of concrete lining (Chainage 0+385.330)

Because of rock class I, II, III with weep holes, and under the initial support, the surrounding rock has been stabilized, so the single-sided reinforcement is adopted.

(1) Calculation of main reinforcement

Reinforcement shall be made according to elastic stress method. Calculating is carried out according to the formula (refer to Figure 4.2.4-1).

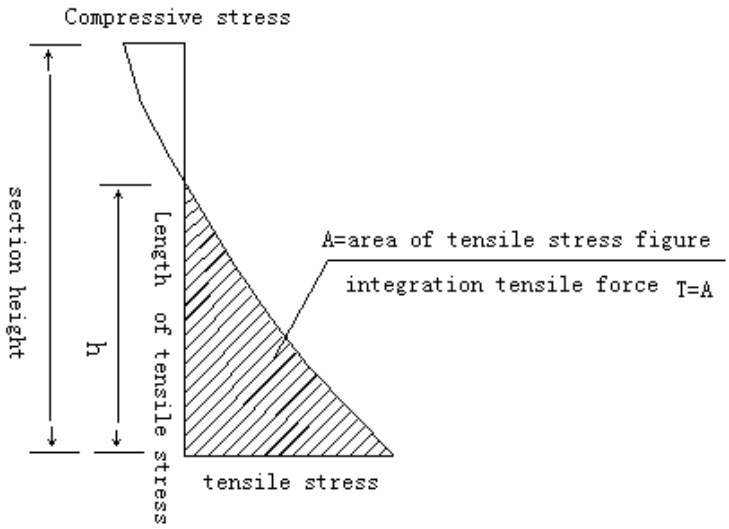


Figure 4.2.4-1 Schematic diagram for tensile force integration

$$A_s = \frac{T}{\phi f_y}$$

$$\mathrm{T} = \mathrm{A} \times \mathrm{b} \int_0^h \sigma dx$$

Where,

A_s——Area of non-pre-stressed longitudinal tension reinforcement;

f_y——Specified yield strength of reinforcement;

ϕ——Strength reduction factor, ϕ=0.9;

T——Tensile force;

A——The area of tension stress;

h——The height of tension stress;

b ——The width of tension stress;

σ—— Tension stress on section.

After calculation, the internal force is list as follows:

Table 4.2.4-1 Internal force of each case

Combine case	Location	Moment (kN.m)	Axial force (kN)	Element No.
Construction& Dry season operation	Invert	***2.6***	***-12.3***	3
	Side wall	16.8	-123.0	34
	Roof	15.5	-770.9	45
	Location	Shear force (kN)	Axial force (kN)	Element No.
	Invert	48.8	-13.7	1
	Side wall	***139.2***	***-342.7***	37
	Roof	97.4	-564.5	41

Note: the axial force compression is negative (-), and tension is positive (+).

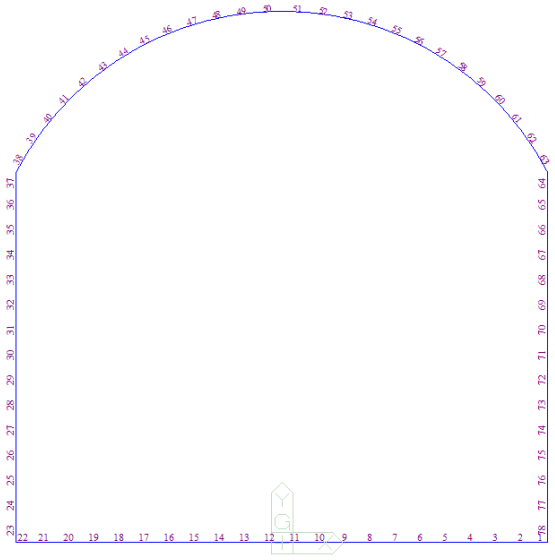
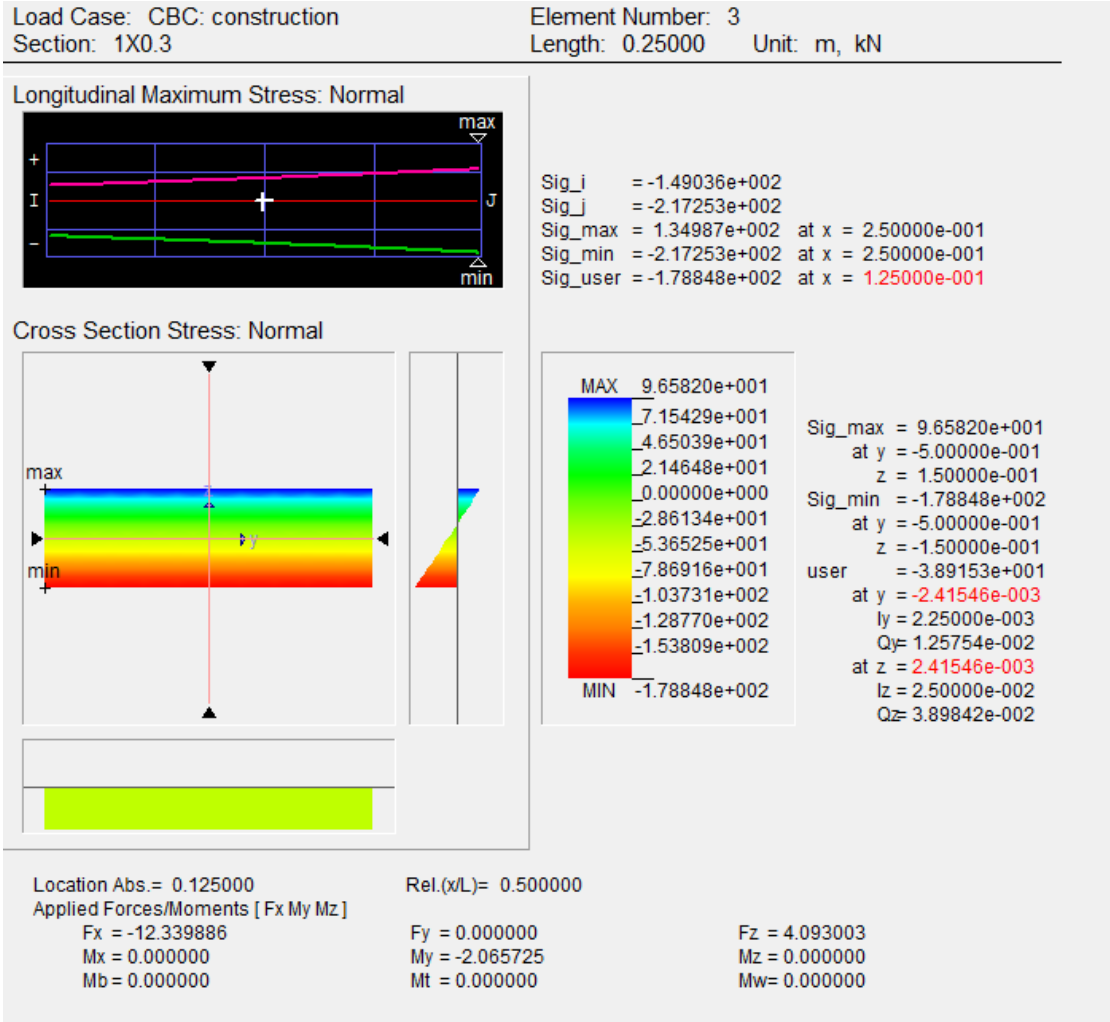


Figure 4.2.4-2 Display of element numbers

According to the internal force calculation results, the reinforcement of ***No.3*** is calculated as follows.



The tensile stress is σ=138x1/3=46kPa, and the result of reinforcement is listed in following table 4.2.4-1.

Table 4.2.4-1 Calculation result of main reinforcement

σ(kPa)	b(m)	h(m)	A(m^2)	fy(MPa)	ϕ	T(kN)	As(mm^2)	Reinforcement	A(mm^2)
46	1.0	0.15	0.15	500	0.9	6.9	15.3	D16@220	914.1

(2) Shear capacity recheck as ACI 318-19

Calculate shear resistance at section according to ACI 318-19

$$V_s \geq \frac{V_u}{\phi} - V_c$$

Wherein:

V_u is maximum shear force at the section;

V_c is shear force borne by concrete;

V_s is shear force borne by reinforcement.

a) For components bearing axial tension, the maximum shear force borne by concrete is calculated by the following formula according to 22.5.5.1(a) in ACI 318-19.

$$V_c = \left(0.17\sqrt{f_c'} + \frac{N_u}{6A_g}\right) b_w d$$

Wherein:

N_u is tension obtained from calculation, which is negative.

b) According to 22.5.5.1(b) in ACI 318-19

$$V_c = \left(0.66(\rho_w)^{\frac{1}{3}}\sqrt{f_c'} + \frac{N_u}{6A_g}\right) b_w d$$

Wherein:

N_u is compression obtained from calculation, which is positive

As is area of non-pre-stressed longitudinal tension reinforcement

b_w is web width of section

d is distance from extreme compression fiber to centroid of longitudinal tension reinforcement

ρ_w is ratio of As to $b_w d$

(c) For components bearing shear force and bending moment only

$$V_c = 0.42\sqrt{f_c'} b_w d$$

According to 22.5.8.5.3 in ACI 318-19, area of shear stirrup is calculated by the following formula

$$V_{ss} = \frac{A_v f_{yt} d}{s}$$

Wherein:

A_v - Area of shear stirrup

s - Spacing of shear stirrup

f_{yt} - Yield strength of shear stirrup

d - Effective height of shear stirrup

Shear resistance of bent reinforcement is calculated by the formula

$$V_{sb} = A_v f_y \sin\alpha$$

Where: α - Included angle between bent reinforcement and component

$$V_s = V_{ss} + V_{sb}$$

The shear force reinforcement result is listed in following table 4.2.4-2.

Table 4.2.4 -2 Calculation result of shear reinforcement of arch springing

V(kN)	Nu(kN)	b(m)	h(m)	Ag(m^2)	f'c(MPa)	fy(MPa)	ϕ	Vc(kN)	Vss(kN)	Reinforcement
139.2	-342.7	1.0	0.075	0.225	24	500	0.75	222.04	0	N/A

Note: the axial force compression is negative (-), and tension is positive (+).

4.2.5 Figure of reinforcement of concrete lining (Chainage 0+413.042)

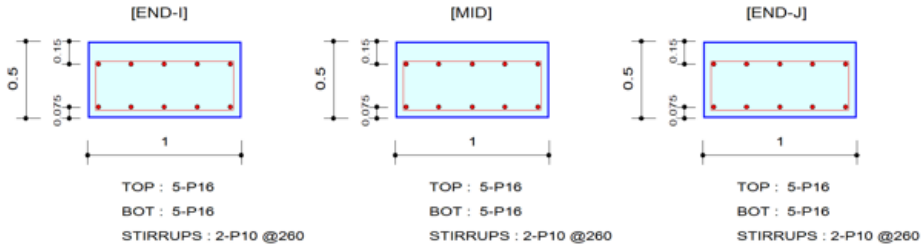
The concrete lining thickness adopts 0.5m.

Reinforcement of invert of CH 413.042

1. Design Information

Design Code	: ACI318M-14	Unit System	: kN, m
Material Data	: fc = 30000, fy = 500000, fys = 500000 KPa		
Section Property	: 1X0.5 (No : 1)	Beam Span	: 0.25 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	9.42	9.30	9.42
Factored Strength (PhiMn)	153.88	153.88	153.88
Check Ratio (Mu/PhiMn)	0.0612	0.0605	0.0612
(+) Load Combination No.	1	1	1
Moment (Mu)	25.91	21.28	25.91
Factored Strength (PhiMn)	187.80	187.80	187.80
Check Ratio (Mu/PhiMn)	0.1380	0.1133	0.1380
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

Reinforcement of side wall and roof of CH 413.042

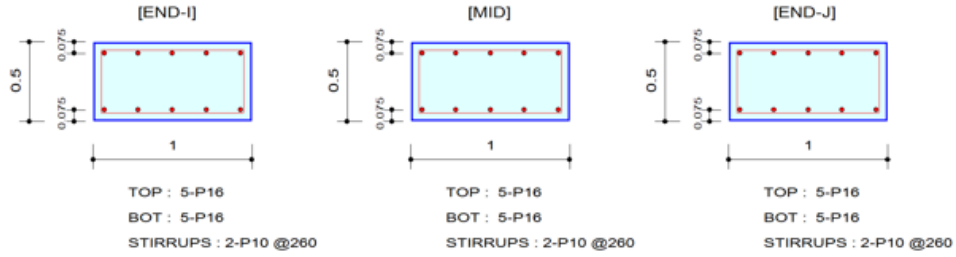
1. Design Information

Design Code : ACI318M-14 Unit System : kN, m

Material Data : fc = 24000, fy = 500000, fys = 500000 KPa

Section Property: 1X0.5 (No : 1) Beam Span : 0.25 m

2. Section Diagram



3. Bending Moment Capacity

	END-I	MID	END-J
(-) Load Combination No.	1	1	1
Moment (Mu)	36.83	37.33	36.83
Factored Strength (PhiMn)	186.69	186.69	186.69
Check Ratio (Mu/PhiMn)	0.1973	0.2000	0.1973
(+) Load Combination No.	1	1	1
Moment (Mu)	73.82	73.51	73.82
Factored Strength (PhiMn)	186.69	186.69	186.69
Check Ratio (Mu/PhiMn)	0.3954	0.3938	0.3954
Using Rebar Top (As_top)	0.0010	0.0010	0.0010
Using Rebar Bot (As_bot)	0.0010	0.0010	0.0010

4.2.6 Shear capacity recheck as ACI 318-19

The shear strength of cross section was checked by new specification ACI318-19, the checking results are as follows.

Table 4.2.6 -1 Calculation result of shear reinforcement

Chaiange	Rock class	Lining Thicknes s(m)	Location	Max shear force of section (kN)	Axial force of section (kN)	Main reinforce ment ratio	Shear force by concrete (kN)	Shear rebar
CH0+006. 000 ~ CH0+020. 000 Inlet	III	0.5m	Whole section	203.4	-413.4	0.004	402.81	D10@ 400X4 00
CH0+175. 039 ~ CH0+195. 039 Intersectio n	III	0.8m	Invert	185	178.6	0.003	310.83	D10@ 334X3 34
			Side wall& roof	191.4	182.9	0.003	307.04	D10@ 334X3 34
CH0+207. 590 ~ CH0+226. 935	IV	0.5m	Invert	142	-63.2	0.003	325.65	D10@ 520X2 60
			Side wall& roof	235.2	-451	0.003	409.98	D10@ 520X2 60
CH0+385. 553 ~ CH0+413. 042 outlet	III	0.5m	Invert	77.1	-27.3	0.003	321.56	D10@ 520X2 60
			Side wall& roof	203.4	-413.4	0.003	404.75	D10@ 520X2 60

5 Conclusions

According to the calculation results of Bending Moment, Axial Force and Shear Force. Reinforcement is follow the standard EM1110-2-2104 and ACI 318.

Contraction joints will be applied with a space of 6.3m, According EM 2104 the minimum shrinkage reinforcement ratio is taken as 0.003.

The Reinforcement Sketch refer to figure 5.1~5.5. Dimensions are in meter, and diameters and spacing of rebar are in millimeter.

Table 5.1 Calculation summary of concrete lining reinforcement

Chaiange	Rock class	Lining Thickness(m)	Main reinforcement diameter & Spacing(mm)	Distributed reinforcement diameter & spacing (mm)	Shear reinforcement diameter & spacing (mm)
CH0+006.000 ~ CH0+020.000 Inlet	III	0.5m	D16@200 Doubled-sided	D16@200 Doubled-sided	D10@400X400
CH0+175.039 ~ CH0+195.039 Intersection	II~III	0.8m	D16@167 Doubled-sided	D16@167 Doubled-sided	D10@334X334
CH0+207.590 ~ CH0+226.935	IV	0.5m	D16@260 Doubled-sided	D16@260 Doubled-sided	D10@520X260
CH0+226.935 ~ CH0+385.553	III	0.3m	D16@220 Single-sided	D16@220 Single-sided	N/A
CH0+385.553 ~ CH0+413.042 outlet	III	0.5m	D16@260 Doubled-sided	D16@260 Doubled-sided	D10@520X260

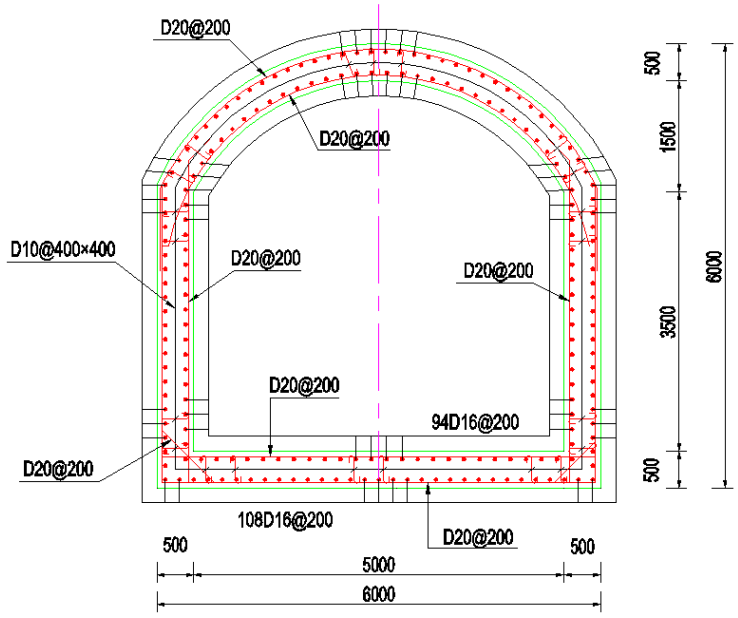


Figure 5.1 Typical cross section (50cm CH6.0~CH20.0)

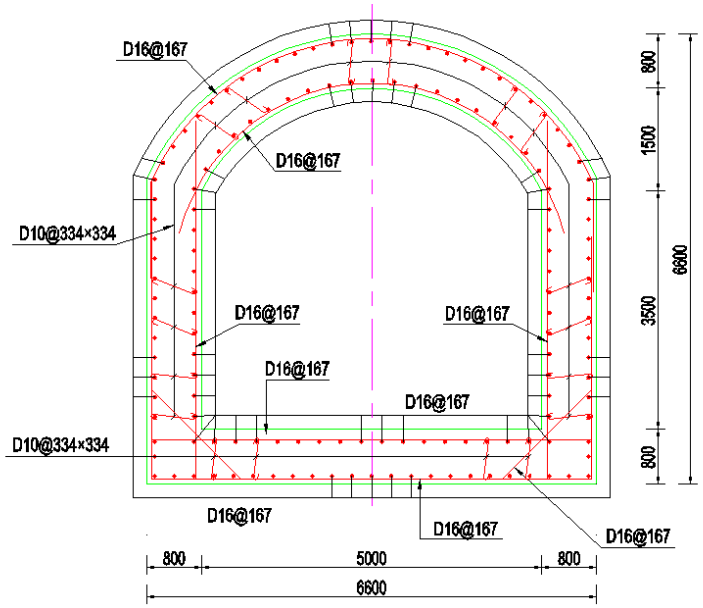


Figure 5.2 Typical cross section of intersection (80cm CH175.039~CH195.039)

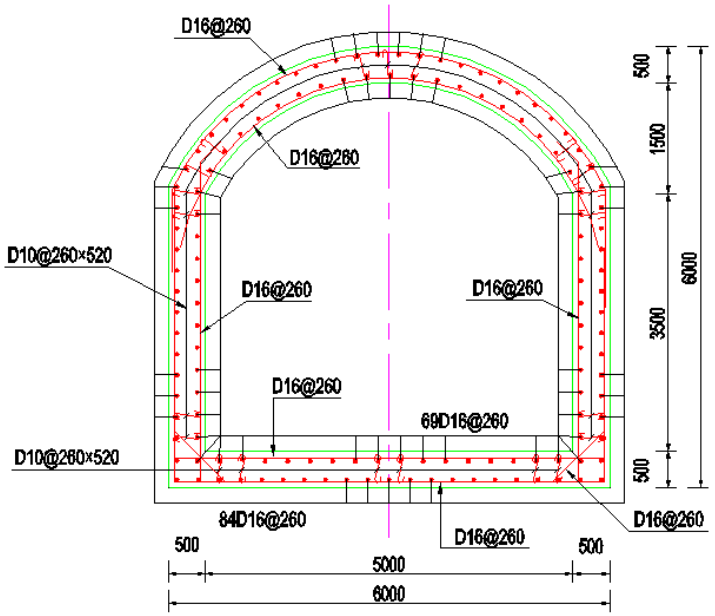


Figure 5.3 Typical cross section (Rock class IV 50cm CH207.590~CH226.935)

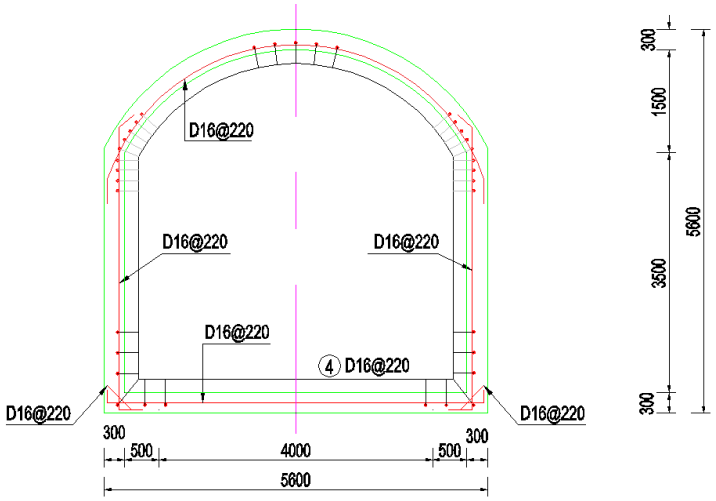


Figure 5.4 Typical cross section (Rock class I&II&III 30cm)

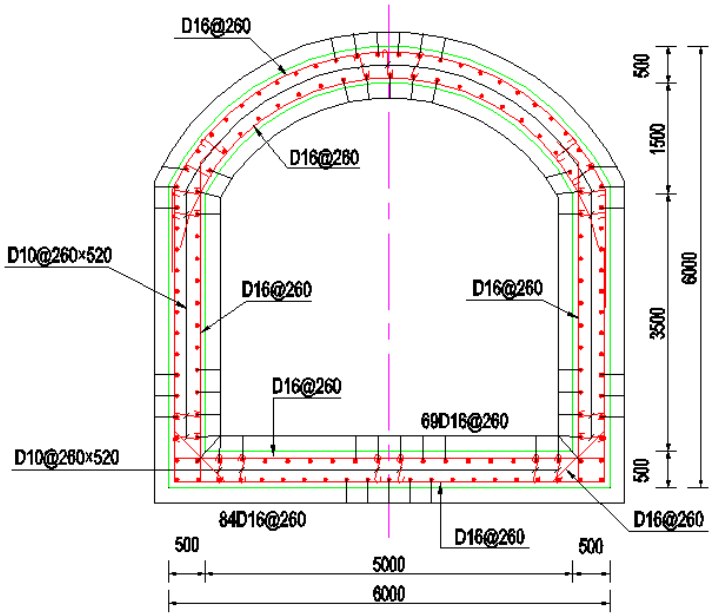


Figure 5.5 Typical cross section (Rock class III 50cm CH385.553~CH413.042)